Managing the Construction of Buildings

Jesper Hundebøl, PhD- student
Learning Lab Denmark
Danish School of Education, University of Aarhus
Contact: jehu@dpu.dk

3D Digital Modelling
– Transformation of Cooperative Practices in Construction

ABSTRACT: Lack of productivity in construction is a well known issue. Despite the fact that causes hereof are multiple, the introduction of information technology is a frequently observed response to almost any challenge. ICT in construction is a thoroughly researched matter, however, the current wave of new building information modelling tools demands further investigation, not least because of industry representatives' somewhat coarse parlance: Now the word is spreading - 3D digital modelling is nothing less than a revolution, a shift of paradigm, a new alphabet...

Research qeustions. Based on empirical probes (interviews, observations, written inscriptions) within the Danish construction industry this paper explores the organizational and managerial dynamics of 3D Digital Modelling. The paper intends to

- Illustrate how the network of (non-)human actors engaged in the promotion (and arrest) of 3D Modelling (in Denmark) *stabilizes*
- Examine how 3D Modelling *manifests* itself in the early design phases of a construction project with a view to discuss the effects hereof for i.a. the management of the building process.

Structure. The paper introduces a few, basic methodological concepts important to appreciate the analysis. Before turning to the presentation of preliminary findings and a discussion of 3D digital modelling, it begins, however, with an outline of industry specific ICT strategic issues.

Paper type. Multi- site field study

INTRODUCTION

Digital Construction (DC)

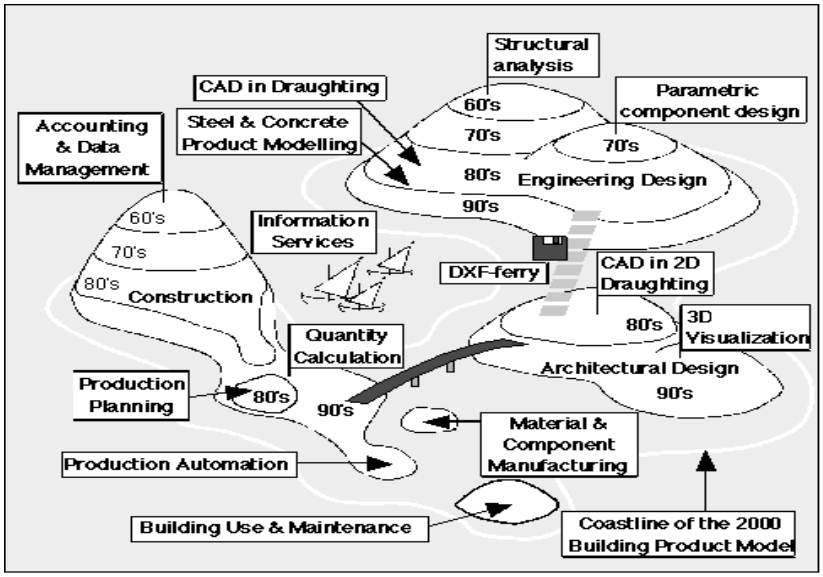
In Denmark, 1 January 2007 was trumpet blasted as D- day: D for digital. As of then architects, engineering consultants or contractors interested in public projects exceeding a 5 million EUR thresh hold must apply through an online project portal. The initiative is generally referred to as *Det Digitale Byggeri (*Digital Construction). DC is a state funded, public- private initiative aimed at stimulating digital integration in the entire building and construction sector. Re- use of data and increased cooperation within (all) actors in the value chain are seen as key drivers towards the end- goal: increased productivity in the sector. As a major building owner the Danish government and it's agencies handling public buildings so to speak *pushes for demand driven innovation* by requiring future suppliers to fulfil certain criteria, among others embracing the so- called 3D Working Method and share 3D drawings on a platform (model server) common for all parties in the project.

To that end the Government has implemented additional rules and regulations in the public building statutory. Prior to D-day actors[1] from all parts of the industry covering almost every type of participating parties in the building processes were engaged.

> *3D is happening with or without the architects*
>
> Ben Wallbank, Architect, Project Director, John Robertson Architects, London, UK[2]

Since extended use of information and communication technology (ICT) and, following that, new and increased cooperative routines are key aspect of DC, I am going to give an account of those two issues in the next few paragraphs. After that I turn to the specific research questions and the particular methodology pursued here. In the last sections I then present and discuss my findings.

INDUSTRY SPECIFIC CHALLENGES RELATED TO 3D MODELLING



Construction IT

Digitalization is not only a local phenomenon. Various concepts and initiatives regarding Building Information Modelling are currently being tested or implemented across Scandinavia (Statsbyg, the Senate), the US (Building Smart), the UK, Germany, Holland, as well as e.g. Australia, Hong-Kong and Singapore. Also, digitalization is not a new trend. The engineering and construction industries embraced computers as early as the 1960s. The first IT-processed algorithms were used for so-called Finite Element Method by structural engineers. Soon computerization of accounting systems was introduced in the business management branch. On a conceptual level BIM (Building Information Modelling) was first introduced in the 1970s; it has been subject to research since then (Lee and Sexton 2007). Later, in the 1980s new hardware and increased processing power, in particular graphic processing capability, allowed architectural and engineering designers to use computers for technical drawings (CAD, Computer Aided Design). In line with accounting, production planning, quantity calculation and estimation software have become common computer applications for the construction industry. Furthermore, CPM (Critical Path Method) was computerized to become a major construction planning software. Then, in the 1990s, continuous increases in processing power gave rise to experimental 3D imaging, visualization and simulation (Lu 2002; Christiansson 2004).

As illustrated[3] the development over the last decades has led to isolated digital islands. *In an ideal* world, design construction (e.g. quantity take off, resource management), maintenance/use (e.g.

[1] 45-50 different consortia and contracts have been established. 300 users are engaged in what is called the "learning network". 600 persons subscribe to the newsletter distributed via the online portal. ("DetDigitaleByggeri").
[2] Source: http://graphisoft.vo.llnwd.net/o1/AC10/RS/BenWallbank.wmv (01 August 2007)
[3] Source: Matti Hannus, 1998-2002 (http://cic.vtt.fi/hannus/islands.html) (currently invalid URL). Reproduced from Christiansson, P. (2004, 23 April 2004). "Education within IT in the Buildning Process." Retrieved 30 April 2007, 2007, from http://it.civil.aau.dk/it/education/overview.html.

hire administration, facility management), and resource supply (e.g. components/material databases) were integrated with formal and informal communication, coordination, and collaboration tools as well as access to external vendor product information, regulations, and community information. *In the real* world, however, this is not the case. More often than not the various software systems are incapable of efficiently exchanging information (Erhvervsministeriet 2001; Hauch, Nielsen et al. 2001; Lu 2002). Furthermore, the various actors have traditionally applied different, specific IT-systems (Erhvervsministeriet 2001: 8-11). In 2005 'bips', a Danish non-profit membership organisation attended by most parties within building, tested the exchangeability of objects between the most common CAD programs. As the test turned out, problems in relation to exchange of 2D geometry were minimal (particularly AutoCAD, MicroStation), in part because of common standards and working methods. In relation to 3D objects, however, exchange was only acceptable within related software applications (e.g. Bentley Architectural and Bentley Structural) – but only if proprietary formats (dwg, dgn) were applied. Knowing that, the test was repeated, now based on the common IFC format. Fortunately the exchange worked better, but there were still problems in distinguishing between e.g. room type and room name (Brinck 2005)(more complex issues are at stake in the front runners' practices). One reason for this is the fragmentation in the industry. The supply chain consists of numerous organizations; together they make major one-off projects. Many small organizations co-exist next to a few major industry leaders. The value chain includes architects, structural and building services engineers, contractors, construction product suppliers, authorities as well as clients. Due to fragmentation among users, software developers, and suppliers at large, no standardized, common it-solution has been developed.

> *We actually took our 3D model and gave them a wire frame of the location of the structure. So they were able to just plug it in and, ehm, and give us some basic calculations. [the model was digitized]. You kind of assign a grid and you assign a zero zero point and then you take a kind of hand scanner, like an arm, and you just kind of pick points. And you make lines, and define where the objects are in relation to each other. And for the purpose of fabrication we can take the whole thing apart so you can kind of get in there with the pen,*
>
> Yoram LePair, PG, Frank Gehry Architects[4]

In sum, investments undertaken in various sub-branches, has not resulted in increased, overall productivity (Erhvervsministeriet 2001). It does not pay-off for the many, small sub-contractors to make comparatively big up-front investments in ICT. Evidently software developers push technology transfer, however, there seems to be a mismatch between a market oriented stance with strategic design concerns and the day-to-day operations (Lee and Sexton 2007).

3D object-based modelling demystified

Dimensions. In 2D modelling the x- and y-axes describes the planar state. In *geometrical* 3D modelling you then add the z-axis which at nobody's surprise represents the height. In *object-based* 3D modelling, however, visual attributes such as e.g. colour and texture is added to the three geometrical dimensions. This allows for visualization and simulation of design options (it is also a cause for frustration, when the façade does not look quite the way the flash-movie depicted). Thus, geometrical 3D modelling is fundamentally different from object-based 3D modelling. You may add further dimensions (nD modelling). Adding a time-element to the virtual object is useful e.g. in order to take account of the spatial conditions on the building site itself - once big trucks need access to various areas on the physical site. Having information about expected availability (in stock, in production, etc) of building materials also allows for managing the many processes. If all prices of materials were embedded in the virtual objects the total cost price of the building could be automatically generated. The virtual BIM objects must be supplied with mutually relating

[4] Excerpt from video footage, Exihibition Digital Construction, Dansk Arkitektur Center, 2007. **Idem for other Gehry excerpts .**

descriptions that can be used in connection with production- and delivery management, staffing, simulation, etc. Normally you would add time sequencing which allows for identifying conflicts at an early stage and for predicting the production schedule (Bips 2007; Lee and Sexton 2007), something that is generally heralded as the major (cost saving) advantage in object-based modelling - clearly it is *that* costly to make changes to the physical foundation. The final destination is nD object-based modelling, or BIM, building information modelling.

> *5D modelling is going to happen, and it is happening already. All the people in the project must change their behaviour and their processes. So I am sure, that it is going to affect the whole industry. Because 5D is the only way in the future we are going to make business, so they are forced to change their ways, otherwise they are off the market.*
>
> Sakari Personen, Project Engineer, Skanska Oy, Finland[5]

BIM. Thus, by 2007 building information modelling (BIM) has become the buzz-word used by most software suppliers within the industry. BIM software must be executed via a central repository which stores all the objects. Likewise other such databases the advantage is that each object is described only once, but applied several times. If an object needs to be modified, you modify only the object once, however, the change is applied everywhere the object is anchored. Graphical and non-graphical documents, drawing and specifications, schedules and any other data, respectively, are included (Lee and Sexton 2007: 290). Complete BIM models or systems cover geometry, spatial relationships, geographic information, quantities and properties of building components, including e.g. manufacturers' details. Quantities and shared properties of materials are to be extracted from the model and scopes of work can be isolated and defined. BIM is able to achieve such improvements by modelling virtual representations of the actual parts and pieces being used to build a building. The most advanced, integrated solutions *promise* to open-up for more integrated building processes, supported by product/process models. Proponents of the technology anticipate that BIM may bridge the information loss normally associated with handing a project from design to construction and through to operation by allowing each group of actors to add to and reference back to all information dealt with during the various phases of the construction process. This is seen as a substantial – almost paradigmatic – shift from the traditional computer aided drafting (CAD) method of drawing with vector file based lines that combine to represent objects. *Clearly the potential advantages are many, everybody says so. Evidently the challenges are multiple, few admits that...*

Finally, on objects. According to 3D Byggeri[6], a local consultancy group, there are three types of objects: Bulk, configurable and systemic deliveries. Bulk objects are simple items such as nails, screws, furniture. Configurable objects are e.g. doors and windows. They can be adjusted on the two planar dimensions, and special types of glass or bars can be ordered. If you pull the virtual frame to make the window very tall or narrow, the object may warn you that it requires a special delivery. A systemic delivery is a composite of configurable objects, e.g. a façade, a roof or a ceiling. Clearly the number of parameters or attributes increases. Although bulk objects are simple, they may be intelligent. If a screw is used in an external wall, the screw would recognize that and define itself accordingly.

[5] Source: http://www.vicosoftware.com/Resources/Testimonials/tabid/46264/Default.aspx (01 August 2007)
[6] Personal communication

From 2D to 3D modelling - traditional organisational practices

Until recently architects have relied on 2D computer aided, document-based design. At time of writing a growing number of drawing rooms take-up 3D object-based modelling - very tangible projects are subjected to real-time tests of the technology. Now, popularly speaking, architects are going to build models (rather than prepare drawings). Some like to show-case their experiences - with a view, perhaps, to position themselves as progressive. Some informants say they *need to* take up the challenge - to stay in the game, end of discussion. They may have listened to national industry representatives, who out-rightly claim that it is a matter of survival[7]. Also, once you have entered into the universe of 3D modelling, there is no turning back - or so they say. 3D computer based modelling is almost a revolution in the industry.

> *In the past it has been a very linear process. About what an architect does before an engineer can do something and what information is available at different steps along the way. We now wee the ability of bringing a lot of the information and knowledge that were traditionally way later in the process - knowledge about how things are build, how fabrication economies occur - we can bring that kind of knowledge a lot earlier in the design process. We think that it empowers the architect, and at the same time we find that it is a benefit for the contractor, who actually has to go out and price the project and build the project. And to the fabricators, who then get a design that is better suited to what they are actually going to build, so, by changing the order of how things are designed and understood, we think that radically changes the whole economy of the process for the better.*
>
> Dennis Shelden, GT, Frank Gehry Architects

Traditionally architects have different styles and working methods. Following in-depth ethnografic studies of coordinative practices among Danish and Austrian architects, Schmidt and Wagner (2004) describe how, in the initial design phases, architects' working styles differ: sketches and pictorial material, poetry and metaphorical text, design based research and cool facts, scale models, and experimentation with spatial configurations. In the drawing room the number of representational artifacts is striking: "plans, sketches, notes, photographs, faxes, books, samples ... scale models ... 3D visualizations ... newspaper clippings. ... What is "remarkable is not just the diversity of artifacts but the intricacy of the workflow". The multitude of artifacts, materials and perspectives are, grosso modo, coordinated and fit into a detailed plan (ibid: 392). However, the "central representational artifact is the system of CAD [Computer Aided Design - the forerunner of and basic element in BIM] plans. They incorporate, as an ensemble, a project's trajectory from draft to implementation; they absorb and reflect all decisions taken and changes made, as plans are gradually detailed and modified." (ibid: 396).

As such architectural plans are based on a sophisticated system of notations and conventions developed over centuries (Jensen 2007). However, in-house standards and classification systems are abundant, and for every project there is a tendency to develop ad-hoc classifications - a red circle may indicate a problem, details may or may not be annotated directly on a print-out, certain items may be highlighted in un-conventional ways. Also, other professions, e.g. the engineers, use different conventions (Schmidt and Wagner 2004).

Large construction projects sometimes involve excessive paperwork - up to a quarter million documents may have to be exchanged. This poses particular strains on both formal and informal communication processes, not least because of the outspoken separation of design and construction (Rowlinson and Croker 2006: 155). To that end the Digital Construction initiative is occupied by allocating new roles and responsibilities within the value chain. Accordingly the architect, the con-

[7] *"Dette er ikke bare for nørder og it-projektledere. Det handler om strategi for virksomhederne, øhh, hvor vil I hen ift jeres målgrupper, jeres samarbejdspartnere, hvad er det for et marked I vil arbejde på, vil I have nogle forretningsmæssige fordele, også i en akkvisitions-/salgsfase, jeres styring af projekter, ved at geare gevaldigt op på IKT-siden, eller vil I fravælge - fremtiden, og forsøge at leve så længe som muligt, indtil virksomheden lukker om, om føje år... Nu skal jeg ikke dramatisere mere end højst nødvendigt, men, men det er nu engang sådan jeg ser det her... (PB1,210607 / P15 : 039)*

sultants, the contractor are required to each of them to assign a person responsible for checking in and out documents on the web server. Data may be re-used but they may also be copied and saved on-line in vast quantities.

Because a major construction project worth more than 1 million euro may last 2-4 years - from the first meeting between a client and an architect until the building is delivered and inhabited, the various teams, e.g. design and construction teams, work together for shorter periods of time, more or less intensively.

> *In a conventional 2D based process, you see that the builders are taking the architects documents, interpreting them and then creating documents of their own. And there is actually a lot of ineffeciency in that process, you loose part of the information, there is a lot of review work involved, on the part of the architect to make sure that they comply. When you work on a single database, and especially if it a 3D database, then the fabricators, the builders, the installers, are building upon something that the architect and the consultants has already developed and, and ehh, gotten approval from the owner.*
>
> *So through the use of more integrated technology combined with communication abilities there is a potential for the design parties to work much more tightly together to reduce the risk of ambitious designs and ambitious processes and for everybody to have a better experience of the building process.*
>
> Marc Salette, GP, Frank Gehry Architects

METHODOLOGY, DATA, RESEARCH QUESTION

ANT - a source for analytical inspiration

Actor-network theory (ANT) is different from most other social sciences – theoretically, methodologically, epistemologically and ontologically... It is something as singular as a "constructivistic, objectivistic/realist, relativistic, non-rationalist theory" (Fuglsang 2004 (2005): 435 (my translation)). The most controversial point in ANT is perhaps the extended application of the Edinburgh School's doctrine of symmetry - that an actor need not be a human (Fuglsang 2004 (2005); Czarniawska and Hernes 2005). This places ANT in an ontologically speaking special category, one that basically grants agency to artifacts (Kaptelinin and Nardi 2007). However, within distributed cognition and studies of human-computer interaction similar approaches is taken by e.g. Edwin Hutchins, who believes that "people, tools, systems, and so on" all are 'media' (Hutchins 1995). Despite the particular approach ANT has become an obligatory point of reference for many social science researchers. The reason is perhaps the unique combination of theoretical and methodological novelty (Harris 2006).

Actor-network theory grew out of studies of science and technology studies. Early science studies, in particular Latour and Woolgar's Laboratory Life (1979) , showed that science does not objectively mirror what is out there in the world. It works within a paradigm, a mind set, within which you can solve puzzles of all sort. The study is an important forerunner of what ANT later became, since the book is a successful example of data combination. According to the work of Latour and Woolgar, the scientific facts produced in the laboratory is a product of interactional work and the generation of a network of relations between matter, inscription devices, people, articles etc. Only when matter, machines, people, etc. have been ordered, persuaded, manipulated, disciplined to play their roles in the network of a new fact, will the fact emerge as self-evident and incontrovertible (Jensen 2003). In an ANT analysis everything is put on the same level - one does not discriminate between e.g. people, power, scripts, materiality, tools. However, *that* is an analytical approach used primarily to *describe* the field. In the end, not everything is analyzed on equal terms. In fact, early ANT is much about power and inequality. Methodologically speaking an ANT

study has an anthropological interest of arranging and ordering all sorts of entities at all kinds of levels. To that end the intricate associations of heterogeneous materials is of great interest.

So, in an actor-network perspective, entities take their form and acquire their attributes as a result of their relations with other entities; ANT is a relational theory that takes account of the dynamics of recurrent, unfolding relations (Emirbayer 1997). Also, likewise symbolic interactionists and Foucauldian post-structuralists, ANT shares the view that relational effects emerge as a result of ordering of the socio-technical world (Gherardi 2000).

ANT inverts most mainstream organizational analytic assumptions that take for granted that actors precede networks (it the tracings that must be put on the map, not the opposite (Deleuse and Guattari 2005 (1980): 29)). ANT (or indeed, Bruno Latour) is indefatigable in turning thing around, asking, i.e. whether the "computer system is a limited form [of] organization of if an organization is an expanded form of computer system" (Latour 1996). Thus, for researchers of information systems - software packages, standards, rules, methods and conventions are for the most part fitting examples of how socio-technical relations impact modern organisations (Doolin and Lowe 2002).

The most important concepts in most ANT analyses are perhaps actor, network and translation (Jensen 2003). I will elaborate on these concepts in the sections that follow, illustrating how the concepts apply to the specific study in question.

Actor

In Bruno Latour's words an ”actor” is a semiotic definition: it is something that acts or to which activity is granted by others (Latour 1996). It is anything that is ascribed agency or admitted to be the source of agency in a situation. Likewise the word 'network', an 'actor' is sociologically biased in that most writers take for granted that an actor is a human actor. To overcome that issue Latour would have preferred the term actant, since it is less biased.

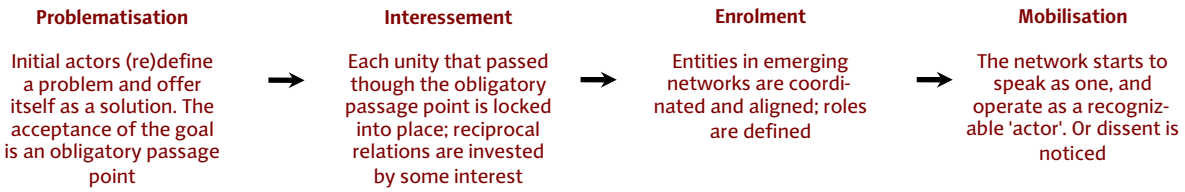
> *First thing it to find a common point between computer and the model... lock everything down so that it doesn't move before the end of the digitize... caputure three points, the origin, x and y... the whole set-up. Laser scanning... Point clouds... projecting a calibrated laser on to the scanned subject. A digital video camera then records it, the distortion of the projected light, allowing the capturing software to calculate the surface geometry. [several sets of data are combined into a point cloud].*
>
> Kurt Komraus, GP, Frank Gehry Architects

Network. Writers of Science and Technology (STS) and others sometimes prefer different brands such as sociology of translation, (socio)material semiotics, or, as ANT has displaced itself from its original belief in the possibility of drawing everything together in a single account (heralding the winner), the term actant rhizome ontology has been mentioned (Hetherington and Law 2000). The latter has distinct references to Deleuze and Guattari's metaphor of the rhizome (in botany a horizontal stem of particular plants, e.g. lyme grass); it is ideal to conceptualize and contrast the ANT-version of a network from most popular conceptualizations such as the World Wide Web or a network of highways. According to the philosophers in question a rhizome is composed of directions in motion: It operates by variation, expansion, conquest, capture offshoots. It has no beginning, nor end, but only a middle from which it grows. In fact, you may conceive of it in many ways, turn and modify it, detach, connect or reverse it. In short, it is an acentered, nonhierarchical, non signifying system (2005 (1980): 29). I tend to subscribe to it, not least because the idea of multiple entryways and exits seems methodologically ideal in relation to one of the most simplified, but also useful mantras in ANT, namely to *follow the actors (*as such ANT is inspired by the work of Harold Garfinkel (1967)).

Also, the network in the ANT sense does not possess structural properties. It never exists independently of the analysis. There are no systems of nodes and lines that lie out there waiting to be discovered, but the analysis goes on until there is a certain saturation of factors and mechanisms that can explain recurring processes of stabilization. Heterogeneous chains of humans and non-humans alike adhere in networks, make associations and acquire identity, and only then become actors, by repeatedly performing the same actions with similar results. Successful network of aligned interests are created through the enrolment of sufficient bodies of allies and the translation of their interests so that they are willing to participate in particular ways of thinking and acting that maintain the network. The process of alignment is one that stabilizes some actors (to become super-actors or, by reference to Hobbes, Leviathans) at the expense of others. In ANT power is the effect of actions and not the cause - even objects are relationally constructed. Stability is achieved through contests of programs and anti-programs; though durable, actor-networks are not fixed – they only appear to be (Czarniawska and Hernes 2005).

> *The Integration of all types of project Information Into a single, collective database Is both an exploratory process, so It Is a divergent process that looks at many different solutions but it is also a process of conversion where you're bringing together and focusing a project onto the chosen direction, direction of design, structural system, and so on and so forth, It's not just about building a one-to-one static model of what you want to put together, It Is actually about exploring a process, and looking at all kinds of different solutions, and testing whichh are the right solution, and then Integrating the Information for the way forward.*
>
> Cristiano Ceccato, GT, Frank Gehry Architects

Translation. According to Michel Callon, translation is the "mechanism by which the social and natural worlds progressively take form. The result is a situation in which certain entities control others" (Callon 1986: 225). Further, to translate is to displace, it is an expression in one's own language what others say and want. It is to establish oneself as a spokesman. (ibid: 214). The translation mechanism is a way to explain how some may represent the many, it is in the translation process that the identity of actors, the possibility of interaction and the margins of manoeuvre are negotiated and delimited (ibid: 203). Callon has defined four moments of translation, that makes the concept more operational, namely problematization, interessement, enrolment, and mobilization (Callon 1986; Callon 1991). The four facets may overlap:

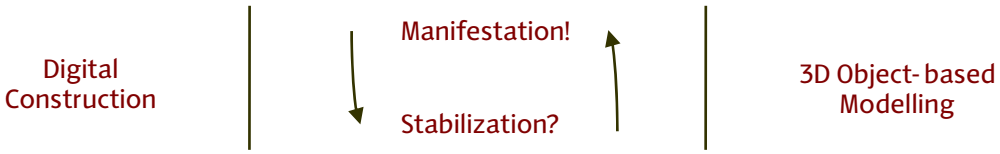


Data. As the value chain in construction is fairly long and subject to e.g. political, economic, aesthetic, social interest, and the field is an elaborate arena of big and small players, humans and non-humans, data come in multiple forms from multiple sources. In this case data is collected in a longitudinal fashion, by combining desk research with multi-site, multi-model ethnomethodological field studies: texts, inscriptions, interviews, observations, photos, video footage, etc. Contrary to traditional experiments aiming at controlling the environment, Latour (2004) argues for a method that is open for *surprises* and unanticipated events, not only coming from the research subject but from all (human and nonhuman) participants involved. Clearly such an approach is likely to generate different questions, more ambiguous data sets. As such, the concept of multi-sited ethnographic research across social and cultural time-spaces is inspired particularly

by the work of Bruno Latour (Marcus 1995). Clearly, in multi-sited fieldwork research, the focus is not a single site. One thus has to rely on a strategy that takes as its focus of investigation the connections and circulations between multiple sites. This can hardly be done in advance; it is a iterative process that must be adjusted throughout the research process according to findings, challenges, and shift in focus (ibid: 90).

Research question

I have already outlined the research questions on page one. It hints that the focus of this paper is intricate relations between people and technology; how technology shapes our practice. Indeed, it is preoccupied with finding out how 3D modelling effects the organisation and management of building processes. Having described major trends within digitalization of the industry, it turns to an illustration of the network of (non-)human actors engaged in the promotion (and possible arrest) of 'Digital Construction' (Q1). It subsequently examines the relational effects that the same actor-network seems to have set about by pushing for 3D object-based modelling (Q2). As such the actor-network analysis simply continues - expanding, however, the notion of an actor to (more) non-human entities and artifacts. As illustrated, the concept of 3D working method is analysed, in parallel, on two, inter-dependent levels that influence each other in a circular, reifying process:



Stabilization. To illustrate the robustness of the actor-network promoting 3D modelling I draw on the conceptual facets of the processes of translation, as they have been exemplified by early studies by Michel Callon (1986).

Manifestation. To examine the relational effects of 3D modelling, a number of field observations serve as micro-cases. The complex figuration of human and non-human relations alike, in which 3D modelling enters, has (more or less unpredictable) *effects* on how e.g. the architect's practice is about to be developed. The cases are intended for further discussion of what the relational effects of 3D modelling are in relation to the organisation and day-to-day management of work routines.

As such, I perceive of 3D modelling as a boundary object, something that at the same time is "plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites." (Star and Griesemer 1989: 399) Boundary objects may be abstract or concrete; they are flexible and multi-interpretable in character (Law and Singleton 2005). Keep in mind, finally, that 3D modelling is not just one thing, 'it' is more than one! 'It' is not a stable technology, but a technology in the making. It has multiple representations, depending on the relations in which it enters; who looks at it... For the actors listed above, it is something that solves the problem of low productivity. For the client, it is what he or she sees when the video with flash visualizations of the future building is turned on. For the architect, perhaps, it is a matter of concern in day-to-day operations. In yet others contexts, it is something else.

STABILIZATION

The following is a discussion (not an account of an objective, finite truth) strongly inspired by the sociology of translation. It is as such a direct application of Callon's four facets of translation, as they have been presented above. As outlined in the research question I would like to illustrate one version of how 3D modelling came about in a Danish context. I am not going to roll out the historical back-drop (at least not here), nor do I pretend to give a full and complete report of what has happened - it would take up a lot of space to give a full account[8]. A good summary is found in e.g. the so-called BUR report (Kristiansen 2001). Despite the amount of reports, the full picture may never be drawn; the construction industry is not a singular entity, but a "non-homogeneous collection of organisations comprising various groups of actors playing various roles at various markets" (Kristiansen, Emmitt et al. 2005: 510). As such the following is a sketch only (and, indeed, a constructivist one) of how the actor-network of, among others, governmental and professional bodies, task forces, associations, institutes, building societies, front runners from across the construction industry, experts and researchers, as well as political programs, exhibitions, reports, analyses, white books and an array of sector specific initiatives came about - and how it presumably managed to stabilize itself and speak with one voice... It is an illustration of how the cacophony of *low productivity*, *delays*, *flaws and defects*, *high costs*, *and low deployment of ICT* translated into 'Digital Construction'.

However, it is not only words... Thus, during the last 30 years the productivity is said to lack behind most other industrial sectors, something that was reported already in 1990 (Jacobsen 1990). Then, between 1990 and 1999 annual growth was negative and industry related investments in research and development fell by an average 5 percent/year (The Government 2003). Despite an estimated annual 14 billion EUR turnover in the sector, revenues are alarmingly low – the 6-8 leading Danish consulting engineering companies and entrepreneurs are apparently running non-profit enterprises (Goldschmidt 2007). Likewise, by October 2007 *Skanska* (ranked nine on IC's annual league table (International Construction 2007)), a Swedish-based global player, announced that it will withdraw from the Danish market[9]. After a number of presumably lucrative years in a booming market accumulated deficits accounts to approximately 1 billion DKK!

> *3D, 4D, nD is a big change, you could say, almost a revolution in the industry, and clearly when you say change, you say, you know, resistance by some, and pleasure by others, ehhm, there will be leaders of this technology, innovators and people who want to embrace it quickly, they see it as exiting, there will be people who see this as a threat and something that they should resist in some way.*
>
> Pierre Puyrigaud, Pre-production Director, Applecross, UK[10]

My account begins with one actor - in this case the National Agency for Enterprise and Construction (in truth, from my point of view the obvious actor to follow[11]). That actor formulated a pro-

[8] "Byggeriets fremtid fra tradition til innovation" (IT Taskforce report, December 2000); "Byggeriets Hvidbog" (Whitebook, December 2000); IT i byggeriets fremtid, PPB-rapport (The National Agency for Enterprise and Construction, October 2001); "Det Digitale Byggeri – rapport fra en arbejdsgruppe" (Ministry of Economic and Business Affairs, Taskforce, October 2001); "Vækst med vilje" (The Ministry of Economic and Business Affairs, May 2002); "Byggeriet i Vidensamfundet – analyse og anbefalinger fra Udvalget vedr. Byggeforskning I Danmark" (Udvalget vedr. Byggeforskning i Danmark, 2002); "Debatoplæg til høring om byggeriets kvalitet, effektivitet og udvikling" (The Housing Committee of the Folketing, November 2002); "Staten som bygherre" (The Government, August 2003); "Svigt i byggeriet" (The National Agency for Enterprise and Construction, October 2004); Digitalisering af den kommunale byggesagsbehandling, Idekatalog (The National Agency for Enterprise and Construction, April 2005); "Det Digitale Byggeri" (Leaflet)(The National Agency for Enterprise and Construction, December 2005); "Besparelsespotentialer for det offentlige ved længerevarende samarbejder i byggeriet" (Danish Building Research Institute, 2006); "Vision 2020 – Byggeri med mening (The National Agency for Enterprise and Construction, January 2006)

[9] According to local newspapers (16 October 2007)

[10] Source: http://www.vicosoftware.com/Resources/Testimonials/tabid/46264/Default.aspx (01 August 2007)

gram, so to speak, based on a politically formulated agenda. An agenda, in part justified, by an overall trend placing great trust on the capabilities of information and communication technology. Soon more actors took an active part - the figuration started growing. A large amount of print (*immutable mobiles*) had, needless to say, been enrolled a priori. Together the actors reformulated a problem (too low productivity in the sector), and suggested a solution (digitalization). They secured funding to launch a nation-wide initiative and used, on top of that, the first actor's market position as perhaps *the* single-biggest buyer and thus most attractive clients in the market, to push for change...

According to the translation model, key industry players must get *interested* in developing, in this case Digital Construction. In line with new public management's way of functioning (delegation), industry representatives were invited to formulate, among others, a set of standards (Danish Building Classification) and a 3D modelling working methodology, that the industry itself is later on to obliged to comply with (given they want to deal with that particular client, namely the various state subsidiaries responsible for public buildings - administration, defence, education, health, etc.)... Their combined efforts got legal backing when the public statutory was passed in the *Folketing*. As such, the statutory became an *obligatory passage point* that works in quite a sophisticated manner: It regulates only how the public authorities themselves are obliged to follow certain regulations; as such it does not put any demands on the industry (unless, of course, actors want to stay in the game as an eligible player bidding for future, public construction works). The statutory only regulates how tenders are formulated and what requirements must be met if the sum total for a new edifice exceeds some 7 million EUR. In that case, as a general rule, the design team is required to deliver 3D imaging, and placed them on a common model server. The model, then, is to be handled over to those contractors invited to calculate the price of actually constructing the building. By now reciprocal relations have been established: 3D modelling is now the obligatory passage point. By now quite a large number of actors have been *enrolled*; emerging actor-networks have become coordinated and aligned, and roles have been defined. It is almost as if the network has begun to speak as one, and operate as a recognizable actor.

But dissent looms. Frustration is building-up and more or less regular *anti-programs* are launched. But voices are disparate, not very well associated, and thus not very powerful. Contrary to the above mentioned network they do not manage to speak as one. Indeed, obvious places to voice your frustration, such as the online discussion forum originally associated with the Digital Construction website, get closed in version two of that website. A clever move that cut the budding links between dissidents; indeed the volume and relations that were hitherto transparent were no longer publicly available[12].

It is uphill, anyway, and for reasons well known to industry researchers: The very nature of one-off projects has created "a project rather than a process perspective of production and of investment opportunity, supply chain fragmentation, lack of client leadership, low level of technology awareness and training, necessary up-front investment, ongoing maintenance costs, and resistance to change." In addition, IT-use is "restricted to administrative and accounting functions, or for highly specific technical functions" (e.g. CAD) (Stewart, Mohamed et al. 2004: 155). The incentives among

[11] The story could have started elsewhere I could, e.g., have looked at the various public and private initiatives launched across the globe, in Scandinavia, Germany, Holland, the UK, US, Australia, South East Asia. I could have started looking at the leading software developers, who evidently also has quite an interest in the drive for digitalization. I could have looked in several other directions.

[12] As such it is an excellent example of interessement: According to Callon one need to build (or remove) devices to interest other actors. In the case of the forum it actually linked the wrong people to the initiative. As Callon states it then A interests B by cutting or weakening all the links between B and the invisible (or in this case quite visible) group of other entities C, D, E, etc. who may want to link themselves to B...

the heterogeneous actors differ: architects and consultants are more interested in digitalizing drawings and descriptions rather than establishing a digital foundation for e.g. management of supplies or installation work. To put it bluntly: *It is not their business*. Also, the main contractor's interest is to control the sub-suppliers, but with changing partners the full benefit of IT-investment does not come through... In case it was your program, then, would you, in such an environment, invite dissidents?

MANIFESTATION

At least one question remains unanswered: Are the masses going to get *mobilized;* in other words, will 3D modelling take off, or, will the program be met by stronger anti-programs? Clearly I can only conjecture about that question - remember, it is a circular, reifying research question that cannot be answered, at least not here, at this moment (it is, by all means, work in progress). However, since it is an important, strategic issue with apparently high stakes (involving e.g. organisational and managerial turmoil, investments in expensive computer soft- and hardware (e.g. 3D printers, 3D scanners), hours spend on training and development of virtual 3D objects, maintenance and further development), it is worthwhile to contemplate a reaction. The simple answer would be that 3D modelling will gain ground if it pays off in terms of contracts won/profit versus sum total of up-front investment (time/money spend) - something that is of course also pretty hard to calculate. The not so simple answer is, in this case, based on considerations that include quite a heterogeneous network of interrelated, socio-material issues, such as e.g. the question of data exchange, software integration and inter-operability, development and penetration of the so-called *Danish Building Classification*, recruitment of personnel, training, roles and responsibilities, work procedures, methods and cooperative routines, etc., e.g. check marks, incompatible software, legal regulations that conflict, standards that work like a Procrustean bed, flight of key personnel, indifference or direct hostility, traditions. As such, it is not about technology, but rather, about process change. I will go on examining this.

3D modelling is going to have relational effects on the roles and responsibilities traditionally delegated among the parties of a construction project. Pilot projects indicate that work procedures and methods get challenged; particularly architects and structural and building services engineers' cooperative routines must change. New, expensive software and hardware packages are required; personnel need to be trained. A few, early cases may clarify what is at stake - at least at proto-type levels.

> *I think the implementation of 5D virtual construction will restructure the entire construction industry, in that the role between the architects and the contractors will change, the role between the contractors and the sub-contractors will change, the role between the owner and the entire team will change, the relationship between the team and the legal system will change. Because of a reduction in litigation, we will see a reduction in claims and other losses. I think just in general the whole communication picture will improve dramatically. So I think initially the leading firms, the firms that commit themselves early to this technology and pursue it have a substantial advantage over the rest of the industry.*
>
> Paul Case, President, Urban Building, USA[13]

From sketch to project; re-use of data. It is an acknowledged fact that the construction industry suffers from incompatibility of software systems - it has done so for decades. Although the software houses insist on the promises of inter-operability and compatibility, several informants' experience is that data can not be re-used. In the case of e.g. 3D illustrations made in early phases in e.g. Sketch-Up, data can not be re-cycled in more advanced 3D modelling software such as e.g.

[13] Source: http://www.vicosoftware.com/Resources/Testimonials/tabid/46264/Default.aspx (01 August 2007)

ArchiCAD. If they could, however, the sketch data is not detailed to the degree needed - it matters whether a wall is 3,70 m or 3.72 m (AR, 060807 / P18 : 022). Likewise later in the process. Virtual building objects may refuse to anchor as the architect would like. A window frame may refuse to be snatched to a corner, because the parameters given to the object reject particular set-ups in the software (AR, 230807 / P19). Think about it. Just slightly advanced users of comparatively simple tools such as Word or PowerPoint, particularly in case of drawings and illustrations, may have experienced that the software sometimes behaves contrary to what one might expect...

Virtual objects. 3D programs and objects needed for building the virtual model are overly complex to handle; complaints were aired that the time spend on figuring out how a software program works might be better spend on actually designing houses (AR, 230807 / P19). The development of proper virtual objects is a time consuming business. Furthermore, virtual objects need careful handling (incl. full meta-tagging) to ensure that they may be filed, shared, retrieved and re-used in subsequent projects (ibid).

EU regulations. Furthermore, objects required for building a computer model are not available at a scale one might expect. The suppliers of building materials are not there, yet - far from (O, 060707 / P14 : 024). Perhaps because the use of the few, existing commercial objects risk getting in conflict with EU rulings on competitive bidding (ibid). To that end debates over who actually has the final, legal responsibility for the correctness of objects is another intriguing question - each and every object should hold attributes defining who put that object in the model (A, 060807 / P18 : 058). Something that could cause voices in particularly the drawing rooms to establish anti-programs.

A *Danish* standard. The fact that the recently developed *Danish* Building Classification (DBK) is a *Danish* standard is objected by leading drawing offices that get about 70 percent of their annual turn-over from international projects (O, 060707 / P14). (DBK is not likely to gain ground internationally). As a matter of fact the International Alliance for Interoperability (IAI) has already spent the last 10 years establishing standards for the use of object technology in construction and facilities management. These standards, known as Industry Foundation Classes or IFCs, are already contained within some of the software packages offered by leading firms - the Danish standard might be included, but it is not yet the case. DBK was not ready by D-day and by summer 2007 it still existed only as a spreadsheet - although it is to be on databases (O, 060707 / P14).

Sub-contractors are missing out, completely. A survey documents that only a fraction of the contractors, months after "D-day", have embraced "Digitalization". Among the small sub-contractors, a majority respond that they have either not done anything or that they have abandoned it altogether. A key actor finds it *frightening to observe how the situation is among sub-contractors*. *A very, very big challenge remains there* (PB, 210607 / P15 : 061) In the same vein, also the building material suppliers lack far behind (O, 060707 / P14)

A check mark. One informant tells how the very same versions of the same software programs may cause differences in the way a 3D model is actually represented on users' computer screens, if a check mark is missing somewhere deep down the set-up. In that case, what should have been a highly efficient face-to-*inter*face meeting around the same virtual representation may demand that the design team spend perhaps the first 20 minutes sorting out the problem, trying this, trying that, once they have realized that they do not see the same representation. In this case the check mark, as an actor, may cause several obstacles (A, 230807 / P19).

From 3D to 2D (sic!). On-site observations made in connection with a high-profile 3D project in Denmark give proof to a baroque situation in which highly detailed 3D drawings are actually converted into 2D drawings. The craftsmen actually using the drawings to e.g. make the foundation of an elevator shaft did not have the competences needed to deal the 3D drawings. Furthermore, claims were given that at Frank Gehry Architects only very few whose architects were capable of actually using Gehry Technologies, accordingly the most advanced BIM technology currently on the market (A, 230807 / P20). However, the conversion of 3D to 2D (yes) is not a one-off situation. On a project abroad some of the Danish leaders within 3D modelling admit that 3D drawings must be converted for legal reasons (EN, 210607).

New titles/job descriptions. The various kinds of actors employ a variety of specialised professions, e.g. construction engineers, heating and ventilation specialists, specialists for façades, lighting, etc. Within an architects practice most partners and employees are, apart from support staff, architects of some kind[14] (architects, industrial designers, landscape architects, engineers, constructing architects, technical illustrators / assistants). Now, new job profiles such as e.g. Knowledge Economist, Head of Quality Assurance[15], Multimedia Administrator, or e.g. 'Chief of Methodology', appear in Danish drafting rooms. A drawing room had hired a journalist. On a global scale, perhaps *the* leading drawing office when it comes to digitalization, Gehry Partners in Los Angeles, USA, was by July 2007 hiring an Information Architect[16] as well as a Graphics Manager[17]. Quite clearly the trend is sparked, in part, by the introduction of 3D modelling tools. Those organisations that are big enough to have a librarian to look after the collection of samples and catalogues are likely to employ someone responsible for handling the future databases full of virtual building objects.

An extra workload? The transition to 3D object-based modelling offers several opportinuties - that is true. But it also takes up additional resources: The current archives of physical catalogues and material probes are like to remain in place however, they are bound to be supplemented by collections of virtual objects. Objects that, for one thing, have to be created, later on managed. This is an additional burden. As hinted earlier on in this text, proprietary objects exchanged across platforms (e.g. between actors within the design team) may be troublesome; data can be lost and it takes time to convert and/or recover files. In a printed interview about 3D working method a construction engineer complains about the frequency of software updates (following e.g. new functionality): Projects may last two to five years and it was "entirely inconvenient" to make an update during a project (change settings, etc.). Another drawback was the frequent revisions of

[14] At C. F. Møller Architects, one of Scandinavia's oldest and largest architectural practices, the 305 persons team are distributed according to the following job profiles: "8 Partners, 16 Branch Heads/Leaders, 159 Architects, 3 Industrial Designers, 5 Landscape Architects, 4 Engineers, 29 Constructing Architects, 25 Technical Illustrators/Assistants, 6 Consultants, 7 IT, 29 Administration, 14 Trainees". Source: http://www.cfmoller.com/siteCFM/profiledetail.asp?x=&menu=.1.11684,12346&detail=12346&langcurr=2.1.1 (31 July 2007)

[15] Danish drawing room ArkiTema.

[16] "Gehry Partners, LLP is currently seeking Information Architects with demonstrated computing and organizational skills to coordinate and structure the effective and accurate flow of information in a project team, including with consultants. Information Architects must also be capable of being simultaneously engaged with the overall scope and nature of the project while managing the myriad details of its execution. This requires experienced conceptual and organizational skills with an emphasis on technical proficiency and attention to detail, and strong and clear organization and communication skills as well as experience with a wide range of 2D and 3D software applications." Source: http://www.gehrypartners.com/positions.asp (31 July 2007)

[17] "This is a hands-on position. You will interface directly with architects and designers to determine the project scope and needs to provide the most appropriate graphic solution. You will also support staff members by providing help on proper usage of graphics software, color process, and equipments. You must keep current on trends and technology. This position reports to the IT Director. ... Some experience in video editing is highly desired. Experience with 3D is a plus. ... Keep abreast of trends and developments in IT, particularly design programs, which will enhance the studio's capabilities." Source: http://www.gehrypartners.com/positions.asp (31 July 2007)

the CAD manual (Jensen 2005). Regarding computer workloads, one informant says that it takes a Silicon Valley to work the way publicly sponsored expositions[18] claim is the right way: one common, virtual 3D model, 1:1 - the amount of data explodes (AR, 230807 / P19).

When all this enter into complex figurations no-one can really initially predict the outcome. The associative web - lines of flight - may go in many directions, and include many yet 'undisclosed' actors. Describing the relational effects of the actor-network, methodologically speaking, is a way to give an updated, phenomenological account of what goes on. It is the first step towards understanding and discussing how we want to organise, how we want to relate ourselves - to artefacts and colleagues.

DRAFT CONCLUSION

Sorting out the intricate associations of heterogeneous entities is a way to discuss how we relate to technology - and understand what it does to an organisation. Thus we get in a better position to contemplate appropriate action. What are the relational effects of 3D working method as it stabilizes itself and becomes manifest in practice. Methodologically speaking that is a matter of how the initial actors manage to (re)define their program (digitalization), and make 3D working method an 'obligatory passage point' - by getting it intertwined and embedded in the already complex figuration of e.g. existing work practices. Indeed, will the 3D working method grow to a size and impact where it enrols others' wills by translating what they want and keep reifying this translation in such a way that none of them can desire anything else any longer - has organisational routines, power relations, working methods etc changed to a degree that it cannot be rolled back - or are the various anti-programs forwarded strong enough to uphold resistance against, in this case, 3D working method...

These questions are not answered here, since, unfortunately, I do not yet hold enough data to justify an answer. All I can say, for now, is that the initiative called Digital Construction has resulted in a statutory to which public authorities should submit themselves in the future. When responding to the tender for the next big construction project[19] design teams must supply 3D models in a digital format. Several of the leading drawing rooms as well as the consulting engineers have initiated local pilot projects to test 3D modelling; informants say that once they have set the process in motion, there is no turning back (cf. the *closure* phenomenon).

> *Well I see that 3D technology is ubiquitous in schools, they use it as a design tool. I cant, that's where I am obsolete, because I hate the images. They are dried out, they don't have any life to them. So I still rely on models. sketching, and stuff like that, the old fashioned way. My young colleagues who's coming up do everything on computer. And, they use 3D modelling, they don't build stuff anymore, they don't draw, they don't build, they just go... Ahh, and I presume that very soon, very soon, that eventually someone will build a building that will be very successful that will be considered real architecture. ... The imagery in the computer is face less, they doesn't have any humanity. And so, how do you, how does somebody learn to use that tool, and achieve, and overcome faceless, in-human kind of characteristics. I assume that somebody will, and there already is..."*
>
> Frank Gehry, Frank Gehry Architects

In a world characterized by complexity and uncertainty success and rationality is not always a matter of power. The power to decide enables an actor to push through decisions, however, deci-

[18] E.g. the exposition "Digital Construction" at DAC (Danish Architecture Centre) (spring/summer 2007) and AroS Aarhus Kunstmuseum (autumn 2007).
[19] Worth DKK 30+ million: The first public construction work under the new statutory, demanding that the 3D working methodology is respected, is likely to be an enlargement of the University of Aarhus.

sions does not always come with the predictable, desirable consequences[20]. In other words, you may have the power to initiate a revolution in construction, by pushing for digitalization, but you may not necessarily control the consequences. Whether or not the masses (the entire value chain) get enrolled and mobilized is uncertain.

The various organisational practices in construction will quite likely change - several leading actors have by now initiated pilot-projects adapting various versions of 3D working method - but it may not lead to higher productivity, less mistakes, budgets and time schedules that hold. It may, in stead, lead to even more paper work, more focus on ownership of plans and objects, and, perhaps, a neo-industrial practice in construction. The price per m2 housing may come down, but then it is perhaps at the cost of architectural beauty.

[20] Source: http://www.clibyg.com/temaer/organisationsmodeller (own translation)

LITTERATURE

Bips (2007). 3D Working Method 2006. K. Jacobsen. Ballerup, Denmark.
Brinck, S. (2005). Nye udfordringer med udveksling af 3D og byggeobjekter. Bips nyt: 8-10.
Callon, M. (1986). Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of Saint Brieuc Bay. Power, Action and Belief: a new Sociology of Knowledge? J. Law. London, Routledge and Kegan Paul. 32: 196-233.
Callon, M. (1991). Techno-economic networks and irreversibilty. A sociology of monsters: Essays on power, technology and domination. J. Law. Oxford, Blackwell: 132-164.
Christiansson, P. (2004, 23 April 2004). "Education within IT in the Buildning Process." Retrieved 30 April 2007, 2007, from http://it.civil.aau.dk/it/education/overview.html.
Czarniawska, B. and T. Hernes (2005). Actor-Network Theory and Organizing. Copenhagen, Liber & Copenhagen Business School Press.
Deleuse, G. and F. Guattari (2005 (1980)). Tusind Plateauer - Kapitalisme og Skizofreni (Milles plateaux), Kunstakademiets Billedkunstskoler.
Doolin, B. and A. Lowe (2002). "To reveal is to critique: actor-network theory and critical information systems research." Journal of Information Technology 17: 69-78.
Emirbayer, M. (1997). "Manifesto for a Relational Sociology." The American Journal of Sociology 103(2): 281.
Erhvervsministeriet (2001). Det Digitale Byggeri - rapport fra en arbejdsgruppe.
Fuglsang, L. (2004 (2005)). Aktør-netværksteori eller tingenes sociologi. Videnskabsteori i samfundsvidenskaberne. L. Fuglsang and P. B. Olsen. Frederiksberg C, Roskilde Universitetsforlag: 417-442.
Garfinkel, H. (1967). Studies in Ethnomethdology. Endlewood Cliffs, New Jersey, Prentice-Hall.
Gherardi, S. a. D. N. (2000). "To transfer is to transform: the circulation of safety knowledge." Human resources abstracts 35(4).
Goldschmidt, L. (2007). Budgetoverskridelser i byggeriet. Ugen på spidsen. Denmark, Danmarks Radio.
Harris, J. (2006). "The ordering of things." Sociological Review 53: 163-177.
Hauch, P., M. L. Nielsen, et al. (2001). IT i byggeriets fremtid, Erhvervsfremme Styrelsen: 150.
Hetherington, K. and J. Law (2000). "Guest Editorial. After networks." Environment and Planning D: Society and Space 18: 127-132.
Hutchins, E. (1995). Cognition in the Wild. Cambridge, Mass., MIT Press.
International Construction (2007). News report - IC's annual league table.
Jacobsen, S. H. (1990). Dobbelt op, FRI: 27.
Jensen, H. S. (2007). Kompetencebegrebet - og tavs viden. AGORA 2007. Copenhagen, Learning Lab Denmark.
Jensen, S. E. (2005). 3D arbejdsmetode. Bips nyt: 4-6.
Jensen, T. E. (2003). "Aktør-Netværksteori - en sociologi om kendsgerninger, karakker og kammuslinger." Papers in Organization(48).
Kaptelinin, V. and B. A. Nardi (2007). Acting with Technology - Activity Theory and Interaction Design. Cambridge, Massachussetts, London, England, MIT Press.
Kristiansen, K. (2001). Byggeriet - på vej ud af den fastlåste situation. Og hvad så? Byggeriets Udviklingsråd: 56.
Kristiansen, K., S. Emmitt, et al. (2005). "Changes in the Danish construction sector: the need for a new focus." Engineering Construction and Architectural Management 12(5): 502-511.
Latour, B. (1996). "On Actor-Network Theory: A few Clarifications." Soziale Welt 47(4): 369-381.
Latour, B. (1996). Social theory and the study of computerized work sites. Information Technology and Changes in Organizational Work. W. J. Orlikowski, G. Walsham, M. R. Jones and J. I. DeGross. London, Chapman & Hall: 295-307.
Latour, B. (2004). "How to Talk About the Body? The Normative Dimensions of Science Studies." Body and Society. Special Issue on Bodies on Trial 10(2-3): 205-229.
Latour, B. and S. Woolgar (1979). Laboratory Life: the Social Construction of Scientific Facts. Beverly Hills and London, Sage.
Law, J. and V. Singleton (2005). "Object Lessons." Organization 12(3): 331-355.
Lee, A. and M. G. Sexton (2007). "nD modelling: industry uptake considerations." Construction innovation 7(3): 288-302.
Lu, H. (2002). "Extended production integration for construction (EPIC): An integration system for building construction." Retrieved 30 April 2007, 2007, from http://etd.fcla.edu/UF/UFE0000565/lu_h.pdf.
Marcus, G. (1995). "Ethnography In/Of the World System: the Emergence of Multi-Sited Ethnography." Annual Review of Anthropology 24: 95-117.
Rowlinson, S. S. and N. Croker (2006). "IT sophistication, performance and progress towards formal electronic communication in the Hong Kong construction industry." Engineering, construction, and architectural management 13(2): 154-170.
Schmidt, K. and I. Wagner (2004). "Ordering systems: Coordinative practices and artifacts in architectural design and planning." Computer Supported Cooperative Work (CSCW): The Journal of Collaborative Computing 13(5-6): 349-408.
Star, S. L. and J. R. Griesemer (1989). "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39." Social Studies of Science 19: 397-420.
Stewart, R. A., S. Mohamed, et al. (2004). "An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry." Construction innovation(4): 155-171.
The Government (2003). Staten som bygherre - vækst og effektivisering i byggeriet. O. EBST, Schultz.