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SHAPE SHIFTING – THE STORY OF A 3D MODEL IN CONSTRUCTION

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ABSTRACT

In this paper, we are concerned with the specific effects of a 3D building model produced and reproduced in the planning and construction phases on a particular construction project. We contrast these effects with the policy intentions expressed within a state funded, public initiative that aims to promote so-called 'digital construction' in Denmark. One of the main objectives of this initiative is to ensure better coordination between the different phases of the building project through the application of 3D Building Information Modeling (BIM). The intentions are to improve the construction phase by providing pervasive on-site planning and logistics, where the 3D building model combined with process-data developed and maintained by the individual contractor should facilitate the production of detailed step-by-step production planning in the form of 'production cards'. The empirical findings from the case-study reveal a much less pervasive and more coincidental utilization of the 3D model than envisioned programmatically. We show how the 3D model is introduced into the construction phase in the form of paper based isometric drawings – as a supplement only to the existing practices. While this modest utilization may resemble a failure from the viewpoint of the policy intentions, we suggest that it allows the craftsmen on the building site to actively translate and contextualise the technology in a form relevant to their activities. We suggest that the top-down regulatory intentions of the policy program may be hampered if there is a failure to create room for such local 'contextualization' processes.

1. INTRODUCTION: FROM THE IDEAL OF SECTOR POLITICS TO THE ROCKY EXPERIENCES OF A BIM

Taking an Actor-Network approach, this paper explores factors that explain why policy strategies which perceive technology as an autonomous mechanism which may be thrown into social relations in order to optimize them cannot be maintained. In doing so, it examines how a 3D building model is simultaneously constitutive of and constituted by local practices in ways that is not envisioned in the political implementation scheme advancing the use of said models.

Danish construction has long traditions for strong political regulation in the form of public policy instruments aimed at improving the productivity of the sector. Focus has especially been placed on policies and instruments aimed at reconfiguring the problematic relations between the different actors of the sector (Bang *et al.*, 2001).

Latest, the large-scale policy program Digital Construction (approximately €6.5 million over a four year period) has set out to address the challenge from a new angle. Placing the construction client in the driver's seat, the vision is to develop a 3D building model, which can: *"…bridge the gap between the different trades/companies of the sector"* (Ministry of Enterprise, 2001:17) and *"…give the construction client access to digital data of relevance for the complete building lifecycle"* (*ibid*., 2001:17).

The politically expressed intentions are that 3D building models will enable the linking of information generated by the architects and the consulting engineers during design to the contractors' calculation, planning and production system. Reuse of the information from design and construction in operation and maintenance is also a substantial intention. To realize this objective a three-stringed strategy is envisioned.

The first and third strings of the program concern the design/tender process and the digital hand-over of project material to the client when the construction project is accomplished. None of these strings are covered in this paper.

The second string, which is the main concern of this paper, concerns the logistics and planning of the actual construction process. The idea is that a given 3D model can be subdivided into specific 'production parts', which combined with data on the production methods provided by the individual contractors, supply detailed planning in the form of 'production-cards'. The production card is generated from the 3D building model and can be seen as a collection of information that the craftsmen need to have at their disposal when performing their tasks on-site (bips, 2006: 6) as it contains all relevant information about the completion of the specific production parts, including detailed instructions on the specific assembly procedures. Illustrated schematically, the envisioned strategy is depicted in Figure 1 below.

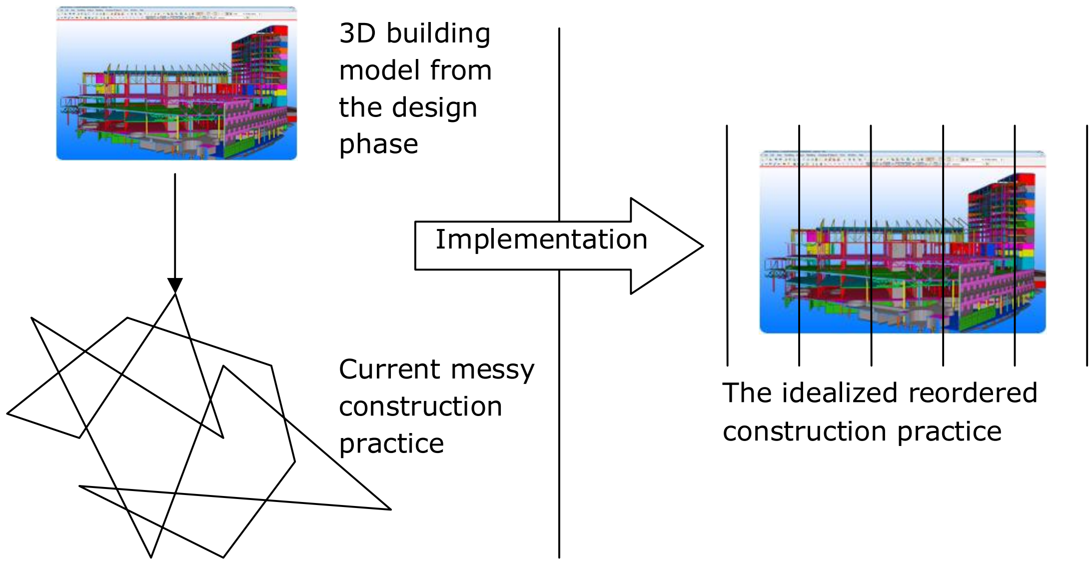

Figure 1. Idealized implementation leading to stratification of practices.

Figure 1 illustrates the rationality of the Digital Construction policy program, i.e. that the current 'messy' sociality or practice of the on-site construction process can be effectively ordered and stratified by the use of 3D building models, facilitating step-by-step production planning reducing uncertainties, redundancy and errors.

By the use of a case study, we challenge this assumption through an analysis of how an actual 3D building model was received and used in a specific construction project. Though this case was not part of the policy scheme we suggest that the case displays general findings concerning the relation between 3D building models and building process which policy schemes need to take account of. The analysis shows that the 3D building model effectively fails to take on the dominant role as it is met with destabilizing forces from the very parts of the project is was designed to re-organize. In particular, we find that for the 3D building model to be used in the first place it undergoes a series of translations that makes the model recognizable and functional in a local context. Thus, instead of constituting a bridge between the different companies of the sector built on the principle of conformity to the logic of the model, the 3D building model is remodeled according to the specific logics of the different actors. Whilst not posing a problem in itself, as the model still is used and functions as an integrative device albeit in a different guise, this raises serious concerns towards the dominant way in which policy implementation is envisioned.

The remainder of the paper is organized into four main sections. Section 2 presents the methodological approach of the study, focusing on the theory, research methods and empirical basis of the study. Section 3 contains the case, which is presented in the form of three storylines. Finally, in sections 4 and 5 we discuss, along the dichotomy of intentional respectively co-incidental enrolment, the results of the study.

2. METHODOLOGY

In analyzing the effects of the 3D building model in the construction process, we draw on the theoretical framework of Actor-Network-Theory (ANT). As argued by Tryggestad (2005) this is an approach which aims to avoid so-called traditional 'human centered' conceptualizations of technological change strategies. Such 'human centered' strategy conceptualizations presuppose technology to be transparent tools which may be controlled and exploited in a predictable way by independent human plans, intentions and rationales. In contrast the actor-network approach suggests that technological artifacts together with humans define strategy as they are made to interact in practice (Tryggestad 2005:40). The approach is accordingly skeptical toward the capabilities of managerial top-down strategies in controlling technological change processes in a straight forward way.

The approach basically draws on the idea of a semiotic materially, meaning that social as well material identities are stabilized by the way they are put to use within a larger heterogeneous network of interacting entities. Thus, according to Law and Mol:

> *"(…) bits and pieces don't exist in and of themselves. They are constituted in the network of which they form a part. Objects, entities, actors, processes – all are semiotic effects: network nodes are sets of relations; or are set of relations between relations. Press the logic one step further: materials are interactively constituted; outside their interactions they have no existence, no reality"* (Law and Mol 1995:277).

An example would be that the identity of a hammer is only stabilized as it is actively put to use (enacted) within a heterogeneous actor-network of, for example, nails, wood, drawings, carpenters and production schedules. The heuristic of the approach accordingly goes that the identity of people and things cannot be taken for granted *a priori* but is always defined locally in specific processes of interactions and associations, which may either be forced or negotiated, and which may be either stable, contented, coherent, or fragmented. This implies that entities only exist performatively, i.e. if they play a detectable role within the production of some specific actor-network formation (Law 1993:131).

Within the actor network framework the concept of translation designates the dynamic evolution or transformation of actor-networks (Callon 1986). Translation designates the strategies (or coincidences) by which entities are enrolled, excluded, transformed or stabilized within the actor-network. Such processes of translation are dialectic processes in the sense that both the identity of the existing or remaining entities within the specific actor-network as well as the entities being enrolled or excluded are affected depending on the effect the translation has on the overall pattern of interaction. Translation is thus the mechanism by which the social and natural world progressively takes form.

Analytically we thus take the position that the 3D building model *is* what it does; how it is enacted in practice, in the actor network or actor world of the construction project. The analytical strategy is to disclose where and how the 3D building model actually manifests itself within the actor network, i.e. in and across the different phases and organizational contexts comprised by the construction project.

To examine this we grant the model a kind of intentionality, of agency, of 'actantiality'. We presume that it is an actor, or, if that is too much, an 'actant'. An actant in the ANT-perspective is an entity, which while being relationally defined is also able to suggest, impose and exclude interaction, i.e. to produce and transform identities by generating asymmetries. We suggest that while the 3D building model is formed as a result of its associations with other entities it also acts within the network.

We thus see actors as 'spokesmen' of performed asymmetries or 'programs' which produce and exclude certain patterns of interaction. Such actors may however be met by other actorial entities aiming to advance alternative and sometimes conflicting anti-programs (Latour 1992:251). Such anti-programs represent an integral part of the social world. They may be encountered head-one in an open conflict, but more typically actorial program face anti-programs through processes of generative translations, by translating itself in order to also translate its adversary.

2.1 Empirical strategy

In order to operationalize the methodological perspective outlined above, we make use of a qualitative case-study approach focusing on a single construction project, which utilizes a 3D model. Following Flyvbjerg (1991), we have adopted the case study approach as it allows us to trace the specific and local enactment of the 3D model presented in a series of narrative storylines. The approach thus positively allows us to avoid a too integrative and essentialist representation of the technology and it effects. The 3D model is accordingly studied from a semiotic or relational perspective in the sense that we investigate *how* it is constituted and translated through its specific relations to managers, engineers, construction workers and other technologies and strategies of organizing and producing order. From this semiotic perspective we follow the development, translations and effects of the 3D model both within and across the different phases and activities of the project.

Our case material stems from an ongoing study within a large Danish contractor and follows a building project that was organized as two separate projects in the same site accommodation. The primary object of the study was the construction of the first of four six storey buildings (238 apartments). The other project on the lot, and in the site accommodation, was the construction of six 6-storey buildings (144 apartments). The total budget of the two projects was €68 million.

The empirical data was collected from ethnographic observations of primarily the on-site processes. In total more than 80 observation days was carried out in a period from September 2007 until autumn 2008. An observer followed the daily execution of work at the building site. The starting point was the site hut and the work tasks of the contractors' project team. The primary focus was on the assembling of the pre-cast concrete elements as well as the installation phase. Data was collected from one-on-one observations directly on the site, from observing conversations in the site office and from attending the site meetings. Moreover a series of qualitative interviews was conducted including the members of the contractors' project team, sub-contractors as well as relevant consultants and suppliers. Furthermore a study visit was conducted to the factory that produced most of the pre-cast concrete elements for the main construction project.

3. STORYLINES – SHAPE SHIFTING

In this section, we outline three storylines from the construction project in question. We illustrate how the 3D building model was developed and enacted in a manner that was not in line with the way suggested within the program of Digital Construction.

The analysis of the empirical findings is used in a general discussion of the processes and strategies through which innovation programs should introduce and advance the use of artifacts like 3D models to complex and institutionalized production environments like that of the construction. This discussion is related to the strategy of the production card as it is envisioned within the program of digital construction.

3.1 The becoming of the model

While most actants come into being as predictable effects of widely performed 'actor-worlds', i.e. as effects generated through well established rules, procedures or taken-for-granted problem-solving strategies, the development of the 3D model was, in this case, most of all the deliberate and personal achievement of the head consulting manager. This is not to say that this head manager brings an entirely new or un-tested being into the world of constructions projects. The idea of building information models within construction can be traced back to the 70s (Eastman *et al.*, 2008); however, the use of such model has not yet been mainstreamed in the Danish construction industry. The decision to use the model is thus a deliberate choice by the head consulting manager, and represents an association in an ongoing and currently very open-ended innovation journey regarding the development and use of 3D building models in the construction industry.

The model is thus not being developed in an environment of activities which is critically dependent on its existence, and which would accordingly be threatened by disintegration in its absence. Rather the model is developed as a somewhat strange existence, which promises new opportunities, but only to the extent that exiting activities and identities is translated, either by force or voluntarily.

Thus, in order to bring the 3D building model into the actor-world of the construction project a series of relatively experimental translations and associations need to be established. Specifically in this case, the buildings are translated into a 3D representation in two software tools called *Tekla Structures* and *MagiCad* used respectively for the building structures and installations. These 3D models were generated from traditional architectural 2D drafting produced in *AutoCAD*.

Already in this very early phase of its becoming the 3D model begins to impose a new order onto the environment in which it is developed. During the 2D-3D translations by which the architectural drawings are translated into a structural model and a series of technical installation models, the traditional actor-world of the company is called into question as the relation between the engineers and the technical assistants need to be re-ordered. As a consulting engineer puts it:

> *"Back in the old days an assistant made the final drawing from the structural engineers sketch. This time the project was made in 3D. And when you design in 3D you must be able to think for yourself. The task is no longer to draw based on the lines on a sketch from the structural engineer. You now have to know what you're doing. Otherwise it won't work. So now it's more blurred who's doing what – and who is capable of doing what! The structural engineer is now also modeling".*

As the modeling process thus presupposes a translation of the existing responsibilities and the working division between engineers and technical assistants, the development of the model crucially depends on the flexibility of the existing associations within the company. As already noted the head project manager is the main advocate, and his ability to achieve the needed translations rely both on his formal hierarchical position within the company, and on his central position in relation to the architect. It may however also be noted that the modeling is primarily headed and performed by young engineers, which are not very strongly associated with the traditional actor-world of the company.

The 3D modeling does, nevertheless, not only translate the professional identities but also impacts on the level of specificity in the design. 2D drawings does not necessarily require objects to be unambiguously defined, whereas the 3D model imposes a binary ontology to the design process, as object can only exist as 'unambiguously geometrically defined'. In the design process the engineers and assistants are thus forced to cope with uncertainties which are normally handled in a later stage in the actual construction phase.

> *"At some point they simply couldn't see, what they were about to draw. It's when you look at the detail-level. It's hard enough to figure in 2D. But working in 3D you're forced to model the details. They simply couldn't see it, and I [the head consulting manager] had to model it for them".*

A crucial prerequisite for the development of the model is also the extent to which the software is developed and tailored to support the modeling process in a manner which is intuitive to the engineers and technical assistants. A destabilizing event is encountered as a software-update hampered the functioning of the software.

> *"We had a lot of problems. Especially when upgrading from version 12 to 13. Theory is one thing but it's something else when it comes to applying it to a large real life project. Normally it's a FAT40 [Human error: Fool At Terminal – 40 cm] but was a buck in the software. Our problem was that we didn't know where and when this failure appeared so we had to do some additional QA. But the building is standing as we speak, right!"*

The challenging binary logic, which the BIM imposes on the design-process however facilitates collision-control in the quality assurance (QA) process, and thus raises the quality of the material considerably. As the construction model is merged with the different installation models collisions between structural elements and installations are thus automatically identified:

> *"All the technical installations are created in 3D – and we've also build the structural model in 3D. We combine the models, and then you're able to see the channeling and pipes. From time to time we've been going through all of the holes in the horizontal division and the basement walls."*

Also the model re-orders the process by which the QA processes are carried out. Rather than carrying out the process on 2D plots and drawings the QA process is conducted directly in the model, and communication also takes place through screen-dumps.

3.2 Co-shaping of model and production world

The scope of ordering accomplished by actants like the 3D building model, i.e. their ability to generate widely distributed effects, critically depends on their ability to act and produce order across organizational borders. During such processes they are dis-embedded from their original performative environment to which they have been tailored and by which they are defined. As a relatively stabilized phenomenon they must be able to enter into alternative performative environments or actor-worlds. Often such processes presuppose that the actant is able to introduce itself in a translated and different version, in order to fit into these alternative performative environments.

As the construction project proceeds from the planning phase to construction phase the ability of the 3D building model to act and produce order across organizational boarders and performative contexts is tested. As a central coordinator of the construction process the executive manager of the main contractor can be seen as an obligatory passage point (Callon 1986). In order to distribute it's ordering effects to the construction phase the 3D building model thus needs to suggest a potentially useful ordering in the eyes of this manager. Critically for 3D building model this executive manager however declares:

> *"I can easily see things in 3D from 2D drawings, whereas other people can't. We have therefore not had any particular use for the model."*

The manager thus, very unfavorable to the model, defines his professional identity by excluding the model from the actor-world of the production site, as he declares himself a professional, because he is able to envisage the project in 3D without the use of the model. The 3D building model thus encounters a crushing anti-program, as it becomes aligned with needs of the unskilled construction worker. The manager also inserts a divide between knowledgeable and ignorant actors in order to uphold his own image of a social order in which the contractors retain their dominant position in the construction process, rather than having to conform to the requirements of the model, and a possible stronger dependence on the consultants.

The anti-program articulated by the manager however proves to be less fatal than it might seem. The main contractor's expectations are to receive the production drawings from the designers 'as usual', i.e. as 2D drawings. They are not the ones who have asked for a 3D model; however, at a common project meeting, the 3D model re-enters the actor-world of the production site in a translated form. On a preliminary plot of the project, the consultant engineer has added a 3D-view of some of the perimeter buildings as supplement to the traditional plan (see figure 2).

In this translated 'analogue' guise, the 3D model succeeds in re-entering the on-site production world of the construction project, as the contractor's project manager approves the design of the plots as the standard format for the project. By translation of format the model thus succeeds to re-enter, while the 3D model in its digital format is excluded from the further production process.

The new shape of the 3D model is a strategy by which it succeeds to cope with the initial anti-program by resembling the traditional ordering methods of the contractor and the project managers understanding of the construction process.

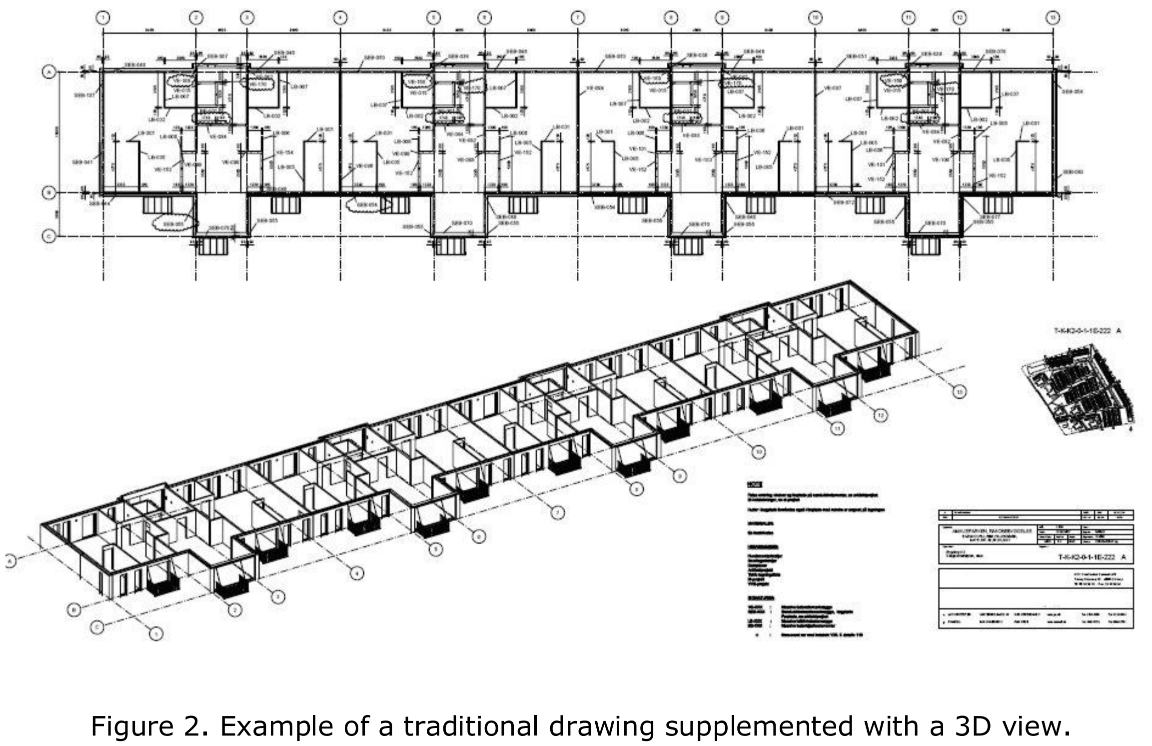

Figure 2. Example of a traditional drawing supplemented with a 3D view.

The ability of the model to perform across organizational boundaries is also tested in the coordination between the consulting engineer and the manufacturer of the precast concrete elements used in the construction of the carcass. In this example the model succeeds to produce a coordinating effect, not however as a digital model, but again as a paper based production-plot generated from the model. This time the 3D model faces another anti-program of a non-human origin as the programming of the machinery used at the manufacturers' factory cannot be controlled through digital 3D information.

Only as a paper plot does the model gain access to the working process and at the factory it is translated once again into the standard production plot that is used by the manufacturer. And so, yet again it is in a shape defined be the existing performative associations of the traditional actor-world that the model finds its way ahead in the building process.

During the process, in which the digital model is translated into 2D production plots an error which later has severe consequences for the construction phase, is produced. The 3D-2D translation requires a manual numbering process, and due to an error in this process the manufacturer is provided with a flawed production order. The entire production process becomes delayed due to this communication error.

3.3 The in-situ reception of the model

With the acceptance of a 3D drawing on the assembly-plots, the craftsmen on-site were offered a new additional actant by which to order their production activity. On-site it was, in strong contrast to the reception in the project management team, received very well by both the production managers as well as the foreman, who used the visualization as an aid in the planning and communication of tasks.

A weekly planning meeting, where all the members of the concrete assembly work gang participated, is an example of how this new actant was tentatively negotiated and performatively defined within the site production processes. Here the executive production manager placed the drawing on the notice-board, and informed the gang members of the specificities of the project and of the imminent tasks.

> *"They [the consultant engineers] have made all their drawings in 3D, so you can see them plotted in the corner of the normal drawings. This way it's easier to see what have to be done to the façades, partition walls, and sanitary cell units."*

The ground assistant to the crane operator then proceeded by taking the plots with him on-site, as the production manager argued that it is highly beneficial in that it enables the crew to quickly orientate the concrete elements the right way. The foreman was however more skeptical towards the 3D drawing and its possible ordering effects in the actual assembly process:

> *"…even though there is a 3D model, no one will look at it on-site."*

The foreman thus excludes the 3D drawings as a means to organize the assembly process of the concrete elements, and the concrete assembly work gang sticks to their traditional methods of how to order and organize the process.

As the gang has to assemble the precast concrete elements on the first floor they accordingly repeat the assembly patterns on the ground floor instead of consulting the 3D drawing for instructions. Unfortunately, the walls had been mounted the wrong way around on the ground floor by the previous work gang. Thus, even though the gang which assembled the ground floor had been replaced, their work still impacted the subsequent work in a somewhat unexpected manner.

In this situation, the gang thus fails to integrate the 3D plot as an actant which may help to order the assembly processes, although it has been suggested that the plot might help to orientate the concrete elements. It is thus the traditional 'method of repetition' which orders the assembly activity rather than the new 3D plot.

4. DISCUSSION

Let us return to the topic of concern raised in the introduction of the paper: the strategic question of how existing social relationship may be developed by means of building information modeling; however this time discussed in the light of the previous three accounts of the actual use of a 3D building model in a specific construction project.

The analysis of how the 3D model actually *makes its presence felt* in the evolving actor-network may be illuminated with reference to the ANT-concepts of mediators and intermediaries. Intermediaries designate entities already stabilized within a specific type of actor-network such a construction projects. These are entities, which may be counted upon as tools for generating controlled and predictable effects. Mediators on the other hand, designate entities whose utilization and effects are contented or uncertain, as they have not been integrated into the 'normal' or institutionalized production within the actor-network formation. Thus according to Latour:

> *"Their input is never a good predictor of their output; their specificity has to be taken into account every time. Mediators transform, translate, distort, and modify the meaning or element they are supposed to carry"* (Latour, 2005:39).

We view the 3D building model as a mediator; an entity not yet constituting a mainstreamed tool with which to organize and order the actor-network formation of construction processes from design to the on-site assembly. In this perspective it is thus still an open question for what specific purposes the model should be developed and used throughout the construction process. The Digital Construction policy program on the one hand and the three storylines presented above on the other hand, represent two contrasting rationalities in translating the 3D building model into an intermediary.

In the three storylines, it is shown that the existence and the effects of the 3D model is highly unsteady and tentative. Thus, at the very beginning, the model does not exist, as the architect conducts the design in conventional 2D drawings. Only in the hands of the consulting engineers are the drawings translated into a 3D model.

For the consulting engineers, the model is perceived as a means to raise the quality of the project material as it allows for collision control between the structures and the installations of the building design. The 3D model also facilitates communication through 3D visualization and digital screen-dumps. A further effect of the modeling process is that the work division between the technical assistants and the engineers is displaced.

The 3D-model 'survives' the first meeting with the construction site by taking the form of a 3D-plot on the traditional production drawings; however the actual purpose and utilization of the 3D plot is uncertain and contested. It is thus suggested that it may be used for planning purposes and also in the specific assembly process of pre-cast concrete elements.

During the assembly process the 3D plot however fails to be recognized as a central ordering device. The concrete assembly gang thus only uses the 3D drawing, whenever they themselves judge it necessary. It is seen that in the first place the drawing is not used as intended, and subsequently it is the previously assembled work, which is used as a 1:1 scale assembly instruction.

With reference to French zoologist Pierre-Paul Grassé, Christensen (2007) and Kreiner (2008) the use of preceding work as a central ordering devise can be referred to as 'stigmergy', designating that:

> *"...the traces in the 'terrain' left behind by other actors, stimulate and structure the proceeding activities" (Kreiner, 2008:2; authors' translation).*

The 3D model fails to manifest itself as the central ordering device in conducting certain on-site activities, such as the precast concrete assembly, as it is met with a series of highly durable existing ordering devices, which is not effectively eradicated by the model itself. In other words, the model is continuously negotiated and translated on the basis of different existing institutionalized practices, constituting the normativity of the project.

This is also seen when observing the reception of the model by the different site managers, who believe that 3D visualization is a good idea; however, they also argue that models are of limited use in the practical work as:

> *"...there are too many things that don't work in practice. In the perimeter-blocks project, the engineers have not taken the different terrain data into account, and when you have three men working on the project at the same time problems arise. Drains and installation have, for example, been led out over the terrain."*

In these practical setting the intended use of 3D model is destabilized by the model's own demands for precision, which are difficult to honor in practice. The effects of the model thus cannot be centrally imposed and upheld. Rather, the model is continuously re-contextualized and utilized differently as it enters the various local actor-network formations of the construction project, as illustrated below in Figure 3.

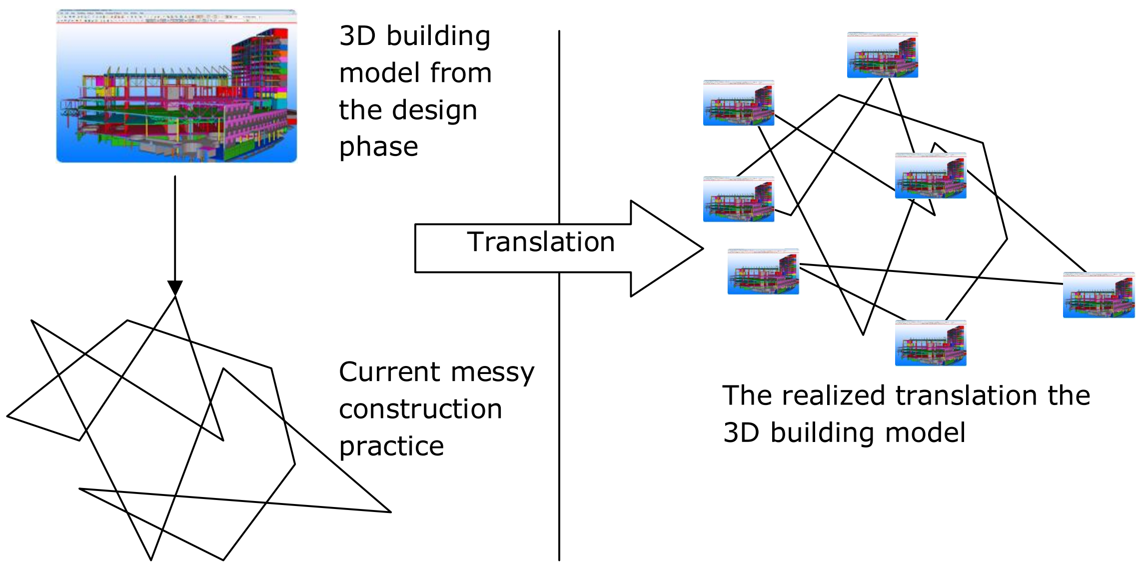

Figure 3. Disintegration of the 3D building model in the realized translation process.

In the communication activities with the precast concrete manufacturer, the model disintegrates even further into flawed 2D production plots, and although we from an ANT-perspective would maintain that the model, as an actant, still exists here, albeit in a highly modified form, it could be questioned, when discussing translation on the level of intentionality or rationality, whether the model has survived in a recognizable form conveying just a fracture of the intended purposes.

5. CONCLUSIONS

The program of Digital Construction may be seen as a strategy aiming to dispense with this lack of centrality displayed in case-study by forcing and prescribing the 3D building model into a pre-defined type of intermediary.

The prescriptive strategy however presupposes that centrally imposed demands will be able to silence the anti-programs voiced within the local actor-networks of construction projects. Very limited room is thus left to the local processes of 'contextualization' identified in the story-lines, which try to define in which specific form and to which specific proposes the 3D building model would be use-full in the specific context of the different local actor-network formation.

A more balanced strategy would probably combine the prescriptive strategy with more systematic processes of 'contextualization' which are less fragile and coincidental than those identified in the storylines.

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