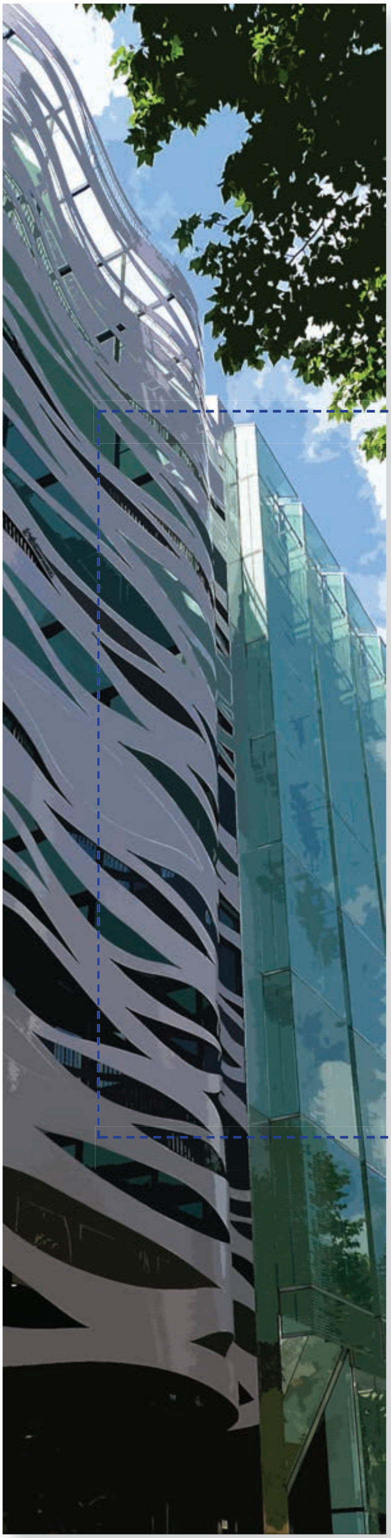

Ole Jonny Klakegg, Kari Hovin Kjølle,
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(editors)

PROCEEDINGS FROM

7TH NORDIC CONFERENCE ON

CONSTRUCTION ECONOMICS AND ORGANISATION 2013

GREEN URBANISATION – IMPLICATIONS FOR VALUE CREATION

TRONDHEIM
12–14 JUNE 2013

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7th Nordic Conference on Construction Economics and Organisation, Trondheim 12.-14. June 2013

FOREWORD

The first Nordic Conference on Construction Economics and Organisation was held in Gothenburg at Chalmers University of Technology back in 1999. Since then, the conference has been held biannually (with the exception of 2005) in Sweden (4 times), on Iceland and in Denmark. Now it is Norway's turn to host the conference, and Finland is scheduled to take over the baton next time. We are very pleased to be carrying on the tradition, and we hope to live up to the expectations created by previous conferences.

In 2011 in Copenhagen an initiative was taken that marked a shift in the organization of this series of Nordic conferences: CREON was founded. The first general assembly was held during the 6th Nordic conference. The CREON network is a voluntary, non-profit association for people who study, work, teach and do research about all aspects of management and construction. The CREON network aims to promote collaboration across Nordic knowledge institutions and this series of conferences is an important activity for CREON. NTNU and SINTEF, as local organizers, are proud to present the 7th Nordic conference on behalf of CREON.

We, the organizers, had two specific ambitions when we started preparing for this conference: Firstly, we wanted this conference to be acknowledged as a high quality academic conference. We have therefore put a lot of effort in the review process. Three rounds of blind reviews is a lot of work, but now when we see the result – it was worth it. The close collaboration with Akademika Publishing makes sure publication points can be awarded to the authors. The papers are presented in two parallel sessions over three days here at the NTNU Gløshaugen campus.

Secondly, we wanted to establish a closer connection with the construction industry. We therefore put together a very strong Program Committee, comprising of prominent representatives from the Norwegian Construction Industry, who identified the main topic: Green Urbanization – Implications for Value Creation. We realized that it was not realistic to turn an academic conference into a popular construction industry event, so we have chosen to collaborate with NTNU in marking their new initiative for improving knowledge about the building process. Thus the idea for the Building Process Day was born – we will spend half a conference day together with distinguished guests from the Norwegian construction industry. The building process day will also be the scene for another conference innovation: Statsbygg awards for best paper and best young researcher. Enjoy!

Ole Jonny Klakegg, Kari Hovin Kjølle, Cecilie G. Mehaug , Nils O.E. Olsson, Asmamaw T. Shiferaw, Ruth Woods (Editors).

INTRODUCTION, CONTEXT AND SUMMARY

The construction industry plays an important role in society. Construction forms our physical surroundings and creates the infrastructure we need to develop society. Physical infrastructure and buildings represent approximately 70 per cent of Norway's Real Capital. Public investments in infrastructure constitute half of all infrastructure investments in Norway. It is also a major factor in the society’s economy, representing a substantial share of the GNP, and, for example, it represents approximately 30% of the employment in Norway. According to Statistics Norway the construction sector is the third largest industry in Norway, employing 350,000 workers in more than 75,000 enterprises, and has a high turnover; over NOK 308 billion in 2011, approximately the same level as 2008 which was a top year. The Confederation of Norwegian Enterprise (NHO) states that the construction industry in Norway provides 10% of the total value creation. The construction industry is truly a cornerstone of our society.

On the other hand the dwellings and construction industry is also mentioned as “the 40% industry” by the Ministry of Local Government and Regional Development. This is a reminder that the construction industry uses approximately 40% of the total energy in our society, 40% of the materials, and produces about 40% of the waste that goes into landfills. This indicates the industry’s importance in relation to climate and other environmental challenges. If there is one industry that really can make a difference, it is probably construction.

Furthermore, the construction industry has a reputation of being conservative, having a low degree of innovation, and low productivity. It is not known to be the first industry to implement sustainable solutions. The construction industry does use low-tech solutions and employ low skilled workers, but it does also include highly advanced New Tech solutions to technical problems and engage some of the most qualified engineers in our society. The truth about this industry is as complex as the problems it is trying to solve on behalf of society.

In the next ten years, growing globalization will promote an already increasing trend of competition among international construction companies according to The Federation of Norwegian Construction Industries (BNL). Additionally, Norway has the following challenges ahead:

- Growing population, expected to surpass 7 million by 2060, up from today’s 5 million
- Increasing trend towards centralisation
- Growing elderly population with needs for health care and housing
- More pressure on transport infrastructure
- An ever increasing immigrant workforce

- Long cold winters and harsh climate, worsened by climate change which may lead to more floods, landslides and frequent winter storms

All these challenges will lead to:

- High demand for new dwellings
- Need for higher investment in low energy buildings
- Need for more robust buildings and infrastructure
- Need for more investment in transport infrastructure
- Need for a larger workforce and recruitment in all sectors
- Need for good integration programmes, development of expertise and training in relevant areas for new migrants and unskilled labour.

These are the sort of challenges that the Program Committee saw when they discussed the profile for this event back at the beginning of 2011. They called it Green Urbanization. The situation calls for new solutions, new knowledge, new thinking. Both small steps and huge leaps help as long as they lead in the right direction. Is the construction industry ready for it?

The sector is fragmented and contains many small enterprises. Thus, large companies account for a smaller share of the construction output in Norway than in most other countries. Small companies with highly specialized competence indicate a fragmented industry. The typical construction project is also said to be one-of-a-kind at a hectic pace. It is obviously hard to optimize process and solutions in such an environment.

Although to a lesser degree than other countries, the Norwegian construction industry is currently facing the challenges that have followed the 2009 financial crisis; small enterprises lost competence due to temporary redundancy and the investments were at a minimum level. Therefore, the diffusion of new knowledge and investments was also at a minimum. To what degree is the construction industry equipped to meet challenges ahead? And to what degree is the academic community able to help this industry overcome its challenges? These are questions that deserve to be asked, and perhaps some answers or indications may be found among the contributions to this conference? Are the academic resources ready for it?

This introduction, its examples and identified challenges are chosen from the Norwegian context, in full awareness of the current peculiarities of the Norwegian situation. We do have a special and advantageous position, but Norway is still clearly a distinct part of the Nordic context. We are also deeply embedded in the bigger international economy and global community. Therefore, the conference profile and the Nordic conference setting feel highly relevant in 2013.

The contributions span a wide range of issues, organized in three tracks with three major themes in each:

Sustainable Development of the Urban Environment	Organizing for Execution	Efficiency in Construction
The Sustainability Perspective	Governance and Strategy Implementation	The Human Aspect in Construction
Sustainable Design	Decision Making and Relations	Productivity and Quality
Sustainability and People	Learning from Construction Projects	Supply Chains and Planning

The first track; **Sustainable Development of the Urban Environment** is the signature track of this conference. It relates directly to the challenges addressed by the program committee back in 2011. The invitation to authors included contributions on sustainability in a wide sense – the concept of sustainability, the framework conditions defined by government and international agreements, the built environment, both the upgrading of existing buildings and finding solutions for future built environments. As the papers of this track shows, the authors cover these issues from several perspectives and cover a wide range of issues as intended. The track provides a varied and thought provoking approach to the term "sustainable"; one of the most oft-used terms in the construction industry today, but which also continues to be one of the most important issues.

Key issues addressed by the papers are; different challenges in combining urbanization and environment respect, the role and use of green certification systems, the role of sustainability in project management, passive house building, renovation and retrofitting from a sustainable perspective and the development of new technology to the deal with climate and age related problems in building materials. Green has become an important issue and two papers look at the role of green certification and policy in stimulating company activity. It can on the one hand, as one paper suggests, become a catalyst, stimulating more green certified buildings. On the other hand, green may mean, as the second example shows, following the market rather than focusing on policies which benefit clients and society. Encouraging a sustainable build is a theme which may be understood as central in this track; it is present in the aforementioned papers and also plays a role in the papers which focus on retrofitting, project management and the building of passive houses. Further issues are exploring the difference between project management success and project success; analyzing collaborative working and experienced effects on the energy performance of a building project; an analysis of existing Norwegian retail development and their impact on local energy consumption; and the effects of user involvement in the briefing and design of a workplace. Scandinavian and particularly Norwegian examples dominate the papers, but there are also case stories from USA and China and contributions from the Netherlands and the UK.

The second track; **Organizing for Execution** represents a combination of new and classic issues around governance, decision making and learning. It covers issues with a wide perspective and long-ranging consequences for the organisations involved. Key issues are governance mechanisms, strategy implementation, decision making, relations and learning. Several papers discuss aspects of governance and how organisations may implement processes and structures in order to improve their value creation and value for money in investments. Examples presented here are the governments in the Netherlands and Norway, as well as several anonymous companies associated with the construction industry. This has a lot to do with designing purposeful decision making processes and using the right criteria for prioritizing and choice of projects. Other perspectives are how to implement necessary transformations of the organization in a changing environment. This is an important issue in a world of increasing globalization, competition and new technologies.

One major topic in several papers is the clarity and better understanding of roles and responsibilities in project organisations and between the project and its mother organization, as well as other stakeholders. These relational issues include communication, motivation, emotions and trust, just to mention some important aspects. The most fundamental topic in these papers is perhaps learning. Learning from cases and accumulating experiences in organisations in construction has been argued a particularly challenging thing to do. Several papers look into these challenges.

The types of organisations represented in these papers range from large public agencies, via industrial companies down to facilities management companies. The projects range accordingly from large infrastructure investments via large building design and development processes down to small and medium sized renovation and upgrading projects in existing buildings. All in all, this track comprises discussions on some of the major issues engaging the research community on construction projects in recent years. The picture is clearly Nordic in the sense that most of the cases reported are documented in the Nordic region, but extended to include Poland, France and the UK.

The third track; **Efficiency in construction** is the original core area of construction economics and organisation, internationally perhaps better known as construction management. It covers both qualitative and quantitative aspects of efficiency in construction. The majority of the papers address the human aspect in construction, but in different ways. Innovation, learning, daily life, scheduling, BIM, productivity, quality, procurement, contracts and supply chains are addressed, among other issues. Roles and interfaces between different stakeholders in a construction project are addressed in several papers.

Innovation is a key topic. It is addressed both explicitly in some papers, and implicitly in many more papers. Innovation in the construction sector is an important topic. It is mainly illustrated through cases. The construction sector is characterised by cooperation between many stakeholders. Design, planning and execution are typically carried out by project-oriented organizations. Deliveries of building components and materials are carried out by manufacturing companies. Interestingly, we also have comparisons between the construction sector and other sectors, as well as the use of analytical models used in other industries but here applied in a construction context.

Contracts and supply chain are addressed in several papers. The contractual relationships in the construction industry are illustrated, with special focus on incentives and stakeholder relations. Planning is addressed in a quantitative way, but from different perspectives. We also have a terminology overview related to planning.

The track includes examples of technology advancement in the construction industry, including Building Information Modelling (BIM).The track includes BIM approaches in a life cycle perspective.

Cases and data come from a wide array of countries, and are not limited to the Nordic region.

The research approaches represent an interesting mix of theoretical work in the form of literature reviews and conceptual papers, development of decision models and understanding of observed performance in real situations, as well as documenting learning from cases and demonstration projects. The empirical side is not surprisingly dominated by document studies and interviews. Several papers are based on case studies. Some papers have a more theoretical approach, while others are very empirical and data driven. In total these proceedings represent a good cross section of contemporary research in the field of construction economics and organization in 2013.

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EXPERIMENTAL DESIGN STRATEGY AS PART OF AN INNOVATIVE CONSTRUCTION INDUSTRY

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Abstract. *This exploratory and conceptual article sets out to research what arguments and possibilities for experimentation in construction exists and if experimentation can contribute towards more innovative construction as a whole. Traditional, -western- construction is very conservative and regional, often following a traditional and linear design process, which focuses on front-loaded cost savings and repetitive efficiency, rather than securing market position through innovation. Thus becoming a hindrance for the development of the sector as a whole. Exploring the effects of using the, in other design-sectors commonly and successfully practiced, "four-phased iterative method" in architectural construction could be the start of transforming the conservative construction industry towards a more innovative construction industry. The goal of this research is to find whether the proposed strategy would indeed result in a higher learning curve and more innovation during the -architectural- process. Preliminary research indicates that there is argumentation for a more experimental approach to construction.*

KEYWORDS: experimentation, design process, innovation, construction, loosely coupled system

1 INTRODUCTION

Innovation, and experimentation in particular in construction is a though topic. In light of negative economic trends, sustainable innovation and future prospects, this exploratory and conceptual article tries to discover what arguments are to be found for experimentation as part of an innovative construction industry and presents a solution which can help to increase the innovating abilities of companies in the Architecture, Engineering and Construction industry (AEC).

1.1 Incentives for a higher innovating paradigm in the AEC industry

The pursuit of knowledge -and the power and wealth that it brings- is the rationale behind innovation. Knowledge enables us to understand, react, expand and control. (Thomke, 2003) The more knowledge we have, the more we can hope to control and the more powerful we are in influencing the way we live (Morris, 2008). Innovation is also a strong measuring factor for success according to the Global Competitive Index (Schwab, Sala-I-Martin, & Greenhill, 2011).

Thomke (2003) states in his book 'Experimentation Matters' that: "*Innovation is the process that creates something new and improves the ability of each person, company or nation to grow and develop*". Saren (1984) gives a similar though more rigid definition of innovation which is dependable on the success of the invention: *"Innovation is the process by which an invention is first transformed into a new commercial product process or service"*

Although paradigms that support innovation in itself are not a necessarily a goal themselves, strong arguments can be made that support –higher- innovating paradigms in the AEC industry. Current –negative- economical market trends as described by Wamelink (2008) and Nelisse & Dieteren (2009) suggest that AEC companies need to innovate and adept in order to regain or improve their economic growth and level of competitiveness. We can describe these arguments as "pushing" forces.

From a "pulling" perspective are changing market demands and future prospects on AEC products in performance, complexity and sustainability, which call for more innovative products and solutions. Companies have to react to these upcoming trends to maintain in business (Braungart & McDonough, 2002), (Ahlberg, et al., 2012) (Ellen MacArthur Foundation, 2012).

We can thus conclude that there are substantial incentives on economical and environmental levels for companies in the AEC industry exist that support a shift towards higher innovating paradigms. This assumption is confirmed by the extensive research by Drucker, (1999) who, in his studies about entrepreneurship and innovation, discovered that a positive link between companies receptive to innovating ideas one the hand and economical growth on the other hand exists, often leading to the survivability and increased leading position of that company in its respective field.

1.2 The AEC industry as a loosely coupled system and its effects on innovation

In Dubois and Gadde (2002) the current AEC industry is looked at as a loosely coupled system. They state that a loosely coupled system is a way to explain the mechanism that is the AEC industry (Weick, 1976). Dubois and Gadde (2002) emphasize that the preferred patterns of couplings in the AEC industry favour short-term productivity and suggests that this hampers the ability to innovate and learn. The industry makes the new pattern of couplings on each construction site an experimental workshop. Though experimental workshops are, from an innovating standpoint, breeding grounds for new innovations, such is unfortunately not the case in the AEC industry.

Learning, Economical growth, innovation and competitiveness relate to each other. (Jiménez-Jiménez & Sanz-Valle, 2011), (Chesbrough, 2003) (Nooteboom & Stam, 2008) (Drucker, 1999). These studies found a relation between organizational learning and organizational performance, which suggest that entrepreneurs who are able to learn and adept stand a better chance of sensing events and trends in the market environment, and even through radical innovation become market changers. The need for organizational learning in the construction industry is identified by Franco (2004) who claims that "*learning processes... ...as a critical missing process in conventional construction arrangements"*

In research on innovation systems, learning is one of the key factors (Lundvall 1992). According to Teece (1998) the opportunities for learning are closely related to previous activities and experiences. If many aspects of a firm's learning environment changes simultaneously the ability to form cognitive structures favouring learning become severely restricted. This is a problem because learning is 'a process of trial, feedback and evaluation'. Gann (1996) argues that this process is seldom accomplished in construction and concludes that *'each house is treated as a pilot model for a design that never had any runs'*. It seems to be the case that the pattern of couplings does not foster economies of scale in design, planning, and construction while they are beneficial for economies in manufacturing of building materials.

The lack of learning and innovation are partly accredited to the project based organization of the AEC industry (Dubois & Gadde, 2002). One of the reasons is the temporary nature of projects and no guarantee of future continuity in the working relation with team members.

Based on the research, we can conclude that the structure of the organization of firms within loosely coupled systems, such as the AEC industry, limits the means of innovation and learning. The strongly decentralized decision structure is one of the key reasons. The loose couplings in permanent networks also serve as a barrier against innovations. For example, long term relationships beyond individual projects are necessary for learning and innovation. If the AEC industry pays less attention to project boundaries, there would be more possibilities for (radical) innovation and continues learning.

2 A VIEW ON ORGANISING INNOVATION

In chapter 1.2 we described the Architecture, Engineering and Construction industry as a loosely coupled system. Although this paper focuses on the possibilities for a higher innovating paradigm from a company's perspective, an effort is taken to describe the AEC industry from a markets perspective on the innovative behaviour of the sector as a whole. This would allow for better positioning of a higher innovative paradigm within the AEC industry.

2.1 differences in market dynamics based on innovative behaviour

Pavitt (1984) tries to 'explain similarities and differences amongst sectors in the nature and impact of innovations.' His research led him to the recognition of four different sectors:

- *'Supplier-Dominated';* are sectors such as the agricultural sector and the construction industry with a large number of small companies. Technology is often supplied by suppliers and external R&D institutions, but also by large customers such as governments. Foremost reason for innovation is cost-reduction trough process innovation.
- *'Scale-intensive';* includes for instance bulk materials (steel and glass), food industry etc. The innovative companies are often large companies with their own R&D departments. Most important motive for innovation is the cost reduction (especially process innovation) and development.
- *'Specialized-suppliers';* are devices and instrument construction. Most companies are often small in size and innovation is most of the time send to customers. Not the costs but the performances are the foremost reason for innovation. Product innovations are dominant in this sector.
- *'Science-based';* Are the electronic, chemical and pharmaceutical industries. They often consists out of large to huge companies with own R&D companies which also receive input from fundamental science.

Between these sectors an exchange of technological knowledge occurs. According to Pavitt the relation between market dynamics is subject to stereotypes. The dynamical taxonomy shows the relation between the different market dynamics (Figure 1). The loosely coupled AEC industry, which is characterized as 'supplier dominated' by Pavitt is heavily dependent on science based and scale intensive firms. Also notable, it does not create something itself, but is rather an end user of innovations.

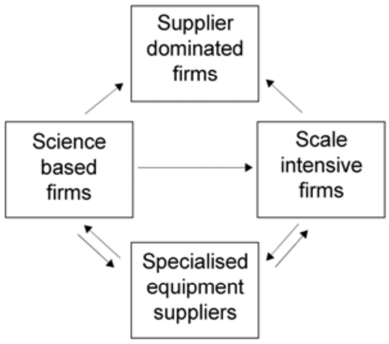

Figure 1; Sectoral Taxonomy

Based on the description of the current AEC industry on its innovative behaviour, we conclude that the current environment as described by Pavitt (1984) and De Jong (1998) does not stimulate innovative behaviour. The current market does not offer companies in the AEC industry the intrinsic abilities to adapt or realize the pushing and pulling incentives as described in chapter 1.1.

2.2 Levels of innovation

We learned that the building industry currently is categorized a supplier-dominated market (Pavitt, 1984). The theory of market dynamics in relation to their level of innovation seems to be substantiated by the work of Freeman and Perez (1988). Freeman introduces and classifies four kinds of innovation levels;

- *Incremental innovations;* These are permanent in every branch. This type of renewal is the result of planned actions, but also occurs from bottom-up by for example the workplace of users of the product. *('Learning by doing' and 'Learning by using')*These changes are small and process-orientated
- *Radical innovations;* These are discontinuous events. They often include drastic changes such as the use of a new material (nylon for instance) which hits multiple sectors at once and can even create new sectors
- *Changes of 'technology system';* These are far-reaching technological innovations that hit multiple sectors at once, but also lets new branches emerge. Changes in technology systems are often the results of a combination of *'incremental innovations'* and *'radical innovations'*. E.g. the first plastics of gunpowder.
- *Changes in 'techno-economy paradigm';* some changes are so far reaching that they have an influence on the whole economy. This is the result from a cluster of *'technology systems'* changes. The invention of micro-electronics or steam power is such an example.

Bers et al. (2009) give the following insight in radical innovation: "*…creates an entirely new set of performance features; improvements in known performance features of five times or greater; or a significant (30% or greater) reduction in cost*". With the shifting market dynamics the construction sector could change from a mainly incremental innovating sector to a more radical innovating sector. The reason for radical changes is described by Bers (2009) who states that: successful radical innovation require a major crisis or market opportunity. If the construction industry wants to develop into a market with more innovative capabilities, the innovative process has to change as well. Based on the market prospects and the change in demands on products from the construction industry, development of the sector's innovation dynamics towards a system that supports radical innovation seems the logical choice.

The research about radical innovation led to the introduction that experimentation is an integral part in reaching radical innovation. (Bers, Dismuskes, Miller, & Dubrovensky, 2009) This is also described by Hekkert (2010) as crucial for entrepreneurs, who need to translate the potential of new knowledge in new market opportunities through experimentation. We can thus assume that with the change to a more innovative construction which facilitates radical types of innovations, experimentation needs take a crucial part in the innovation process.

3. ABOUT EXPERIMENTATION

In his book about why Experimentation Matters, Thomke (2003) describes that according to his studies in the pharmaceutical, computer chip, and automobile sectors the core of each innovative process consists out of a series of experiments which are framed in a four-phased iterative process (figure 2). In his book he claims that by rule all experimentation consists out of iterative attempts to form a solution. These iterations can range from several to tens of thousands. As projects progress and mature, cycles tend to include models of increased fidelity and finally move to complete representative prototypes. Prototypes are used to test structure, design, function and manufactory.

The result of each experimentation cycle is analyzed and used to improve the next round of experimentations. The resulting knowledge comes as much from failure as from success in these experiments.

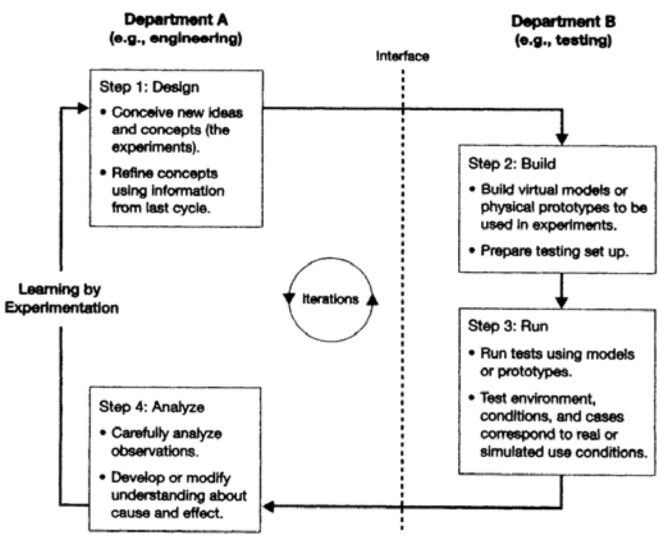

Figure 2 Deterministic model

Every experiment generates information which in turn forms the input for new experiments. However, well structured and integrated into organizations, experimentation and innovation become potential shifters in market, industries and even cultures (Chesbrough, 2003). Visa versa, Thomke states that the rate of learning is influenced by a number of factors. These factors affect different things, ranging from the innovation process to the management of innovation.

3.1 Introducing the four-phased method.

Experimentation is done by iterative attempts to find answers. These "cycles" are here presented in two models, based on the work of Thomke. Both methods are describable as a four-phased method, but vary between deterministic and emergent (Figure 3). They both function on the same principles and the description of the phases is for the most part identical:

- **The First Step** is the start of each typical experiment which begins by selecting one or more possible concepts or designs. Since the outcome is not yet known nor understood, the right concept might or might not be among them. Because the end result is not yet understood, one cannot expect that the solution is among the concepts.
- **The second step** consists of building virtual models or physical prototypes of the design(s). These models are used in experimentation. The focus of each model should solely be on that which is about to be tested. (A paper model of a building is probably no use when testing for fire safety)
- **The third step** is the testing of the concept(s) through a number of experiments. These experiments should be able to validate the desired outcome of the solution such as the requirements and constraints. These tests are known as the trials. Each particular trial will result in new information and learning. The most useful are the experiments that lead to unforeseen failure or error for they enable a higher learning curve until the right answer is found.
- **The fourth and final step** during a cycle is analyzing the test results. Based on these results the design is altered accordingly and the whole cycle is repeated until a desirable result is achieved.

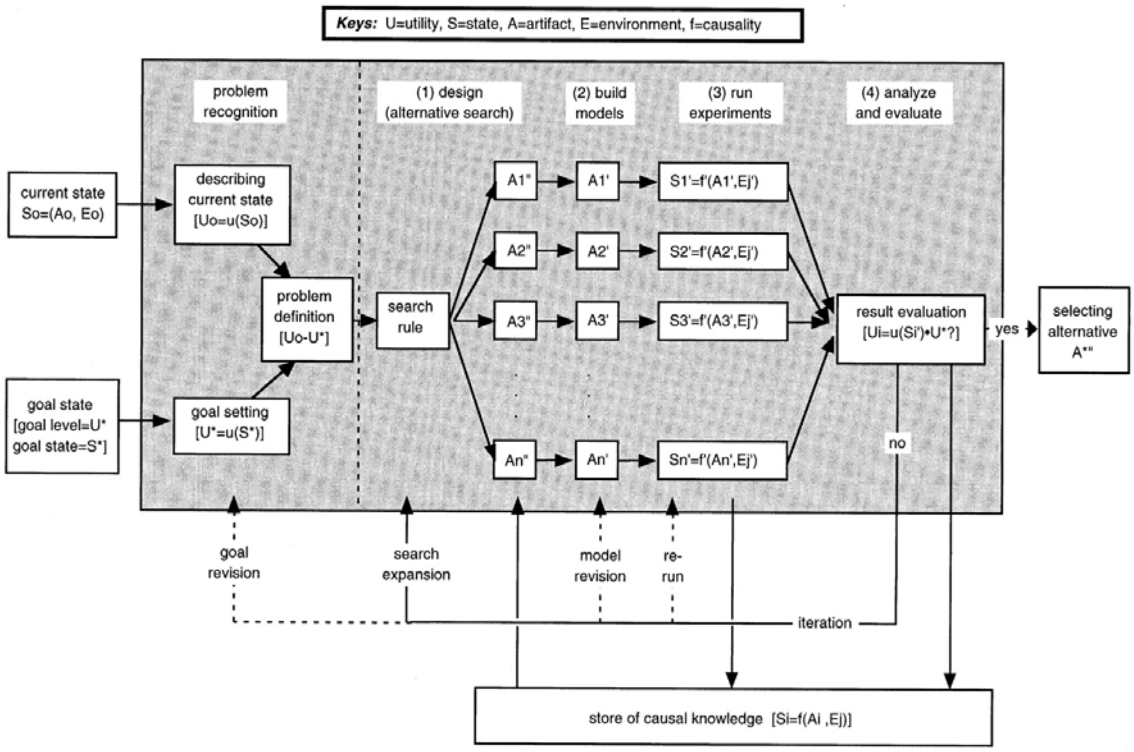

Figure 3 Emergent Model

4. TESTING TWO TYPES OF EXPERIMENTAL METHODS AS TOOLS FOR RADICAL INNOVATION IN CONSTRUCTION

In the above two approaches to experimental design have been presented, deterministic and emergent. Both approaches can be connected to the four-phased method introduced. The research reported tested both approaches to the four-phased method in a construction setting.

The research was carried out by students. First one design model was tested. In advancement to this design challenge an exercise and artefact were devised (to design additional creativity-inspiring space on an existing rooftop) and the new experimental design model was provided and explained. The group designed strictly according the explained model. To maintain objectivity and ensure quality of the design and monitoring the design process weekly sessions with professors and experts took place, during which recommendations and experiences were discussed. Meanwhile experiences were collected from the group. After a period of two months (including 2 weeks of no exercise between the 1st and the 2nd exercise) the same group was presented with the other experimental design model but the same artefact and objective. The same exercise was carried out, but now according to the newly presented experimental method. The new method was modelled partly on the feedback of the first exercise. Feedback and weekly sessions remained the same.

4.1 Deterministic four phased method

First, the previously described four phased method was used as a direct attempt to convert the four phased iterative process into an appropriate design method for construction (Gjaltema, 2012). This experiment was conducted applying a *controlled i.e. deterministic* *design process* to find out whether this method could indeed be translated into a useful design strategy. In practice the use of this method in this manner proved to be difficult, while the process appeared to be relatively deterministic. This notion led to the conclusion that further development of the method into a more open process was necessary, but on the other hand, that it was too early to conclude whether or not such a method would have any merit in real practice.

The application of the four phased method applied to a controlled design process in a construction setting led to the following four key insights:

1. 'The design process needed to be considerably structured; the lack of structure to the design process resulted in 'congestion' of the entire process due to uncertainties. As a matter of fact the uncertainties had to be found out during the course of the design process itself. This proved to be vicious problem to get the design process started and to keep it going.

2. 'The problem definition needed to be structured beforehand'; There was no presence nor possibility to put in place the proper preconditions for a deterministic design process, such as starting the process with description of the current state of the design process, structure to how new demands could be handled or incorporated in the existing design question.

3. 'The use of variations needed to be brought to a parallel sequence rather than a linear sequence'; the goal of the design method was to achieve a steeper learning curve through experimentation and enabling room for radical innovations. However due to the linear setup of the process no argument existed for participants in the process for exploring new possibilities further than the horizon of the stage of the process they had been involved in.

4*. 'Clarity about the following iteration needed in the design process to gain better results'*; this linear design approach followed the 'four cycle process' and eventually resulted in one possible answer. However, in case of a negative or unsatisfactory outcome no clarity was given within the model what the following steps should be to improve the next round of the iterative process. As a result one could conclude that this kind of design approach, although experimental by nature, will probably not have led to radical innovation.

4.2 Emergent four phased method

Rather than the deterministic approach, an emergent approach to experimental design was expected to lead to radical innovation more probably. In the test of this research an emergent process was devised to begin with phase 1, 'design'. This phase started with "design A times N". N is the number of models or testable objects. The next iterative round will be round B, etc. Next, models of the designs from phase 1 will be built in phase 2, 'build models'. During phase 3, 'run experiments', experiments are done on the models. Each criterion that has to be has its own research line. Sometimes this means that more than one model has to be made for the same iterative cycle, to test different criteria accordingly. The results are all combined, analyzed and evaluated in phase 4 'Analyze and Evaluate'.

This will either result in a final product, or in a new adjusted iteration of the model. The adjustments can be made on various levels, such as a rerun of the tests under different circumstances, a new model or even new or more designs. Goal revisions or new searches are also amongst the possibilities. The number of iteration cycles is unlimited, and will go on until a satisfying answer is found in accordance to the problem definition. In this design approach, because of the iterative and emergent elements, radical innovations had been more likely to be achieved.

5. DISCUSSION

The goal of innovation through experiments is to reach understanding and contribute to progressive change (Morris, 2007), (Carlisle & Manning, 1999). Often throughout history progressive changes such as the invention of the microwave oven, vulcanized rubber and penicillin are the results of accidental discoveries during experimentations. And these are only the cases that led directly to inventions that we know of. Given to the notion that the gain in knowledge through experimentation is as often from failure as from success (and arguable even more) (Thomke, 2003), a strong case for conducting broad experimentations with uncertain outcomes can be made.

One could say that 'learning by experimentation' appears to be deterministic. The philosophy about determinism describes that 'Determinism states that for everything that happens there are conditions such that, given those conditions, nothing else could happen'. (Doyle, 2011) Another term which is often introduced is 'cause and effect' (Loewer, 2001). When compared to the above model, the iterations can be describable as 'cause and effect'. The result of one iteration leads to adjustment in the next. However, the adjustments are always reactions on the outcome of the previous round. Therefore, theoretically, at any time during the process only one possible outcome exists (although the outcome might not be yet known).

In light of the lack of innovation possibilities that research on loosely coupled systems suggested, the introduction or use of an iterative model that supports multiple experiments at the same time would be favourable. The results found in Gjaltema's experiment are also described in Saren's analysis of different innovation models (Saren, 1984). He summarizes the same procedure as Gjaltema used as linear. He formulates definition and criticism as *"A straightforward process from stage to stage, and gives no indication of the alternative paths available at particular points in the process. In reality, several such alternatives are possible and the existence of alternatives requires decisions to be made...."*

Perhaps a comparison can be drawn between this method and the evolution in nature. (Darwin, 2009). Through mutation existing species develop and new species come into existence. However, if a mutation shows no improvement or benefit, it fails. (E.g. the species does not survive). One could argue that nature discards her failed experiments. However, with the discarding of experiments the knowledge developed alongside it is also lost. This comparison is an example of what happens in the proposed four-phased method. There is no room for the storage of knowledge and at the same time it would entirely be possible that those failed experiments in other scenarios could have had great contribution to the development of others. The loss of both knowledge and other possible outcomes is contrary to the goals of experimental innovation.

In light of the character of this paper an additional investigation was made to establish the relevance of this document compared to existing work. The traditional organisation of the construction process stood central in this investigation. The conclusion of the comparison with several other studies on comparable topics e.g. (Bakens, 1992), (Louwe & van Eck, 1991), (Louwe & van Eck, 1992) & (Hawk, 1992) was summarized best by this statement: *"In all Western industrialized countries people recognize or are starting to recognize the traditional segmented organization of the building progress as a major problem in general and as a major hindrance for innovation in particular"*.

6. CONCLUSION

Although conceptually, the main conclusion of this paper is that emergent experimental approaches to design are more likely to result in radical innovation than deterministic experimental approaches. In the research the presented design methods were unfortunately tested only once. Although the experiences from this test are no solid ground for the propagation of experimental designing in construction and architecture in particular, it did show appropriateness of the methods applied, and a steeper learning curve than expected. Particularly the second emergent method was effective. The iterative cycles and the hierarchical template of the method provided direction and created an environment in which the testing could take place efficiently without fear for losing track of the progress. This was the case in the first deterministic method.

The steeper learning curve was achieved through the engagement with the proposed variations in each round and active testing on predetermined conditions. Rather than passive testing based on emotions and irrationalities, this method actively looks for the same answers in each model with the same preconditioned values. Although both the active and passive testing engages in the reflection-in-action paradigm, the active testing also engages in conversation *between* the different models trough the use of the standardized logs. Thus being distinctively different from traditional design methods.

By allowing the first cycle to deliver products that were not rigidly based on the problem definition a much wider field of possibilities is opened, thus enabling much higher innovative possibilities. At the same time higher levels of innovation are reached during the cycles where by testing different models the possibilities for new materials and products is stimulated.

The results of this research on experimental design strategies are promising. However, more research is needed before this approach can be used as a valid design method in practice. Research is needed in the mechanics of the method itself. Testing the method on more cases is strongly recommended. Secondly, economic questions such as the time and costs of using this method compared to be other design strategies have to be considered and researched before a complete answer can be given whether this proposed method is really viable as a solution to more innovation and a higher learning curve in the building sector.

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