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INNOVATION DEPLOYMENT STRATEGIES IN CONSTRUCTION

T. Bock, T. Linner, C. Georgoulas, M. Mayr, J. Meyer-Andreaus
Technische Universität München (TUM), Germany, thomas.bock@br2.ar.tum.de

Abstract

In the computer industry, as well as, in the automotive industry, the pace of innovation is already so rapid that within a few years a complete system or technology change can occur. Both industries steadily advance the performance of their products, meanwhile prices remain stable or even decrease. In relation to those industries, especially in construction industry we observe a low speed of innovation, increasing cost and the lack of analysis in construction specific innovation mechanisms. Despite a multitude of strategies and tools for technology, change and innovation management have been developed by innovation science in general, construction specific systemic tools and innovation deployment strategies had not yet been in the focus of research. The authors, therefore, started to build up a new research field that they called "Innovation Deployment Strategies" and systematically analyzed tools and innovation methods, (not construction specific), and innovation mechanisms that can be observed within construction industry, (construction specific), in order to be able to develop a construction specific innovation deployment view. As an outcome of their research the authors have developed the 7-DCI Diagram (Dimension Construction Innovation Diagram), a view on innovation in construction with the aim to provide a framework being able to support researchers and practitioners alike in identifying and generating innovation mechanisms fast and efficient, thus building the basis for a more changeable and flexible construction industry.

Keywords: Automation, Construction, Innovation, Management, Robotics.

1. INTRODUCTION

In the computer and in the automotive industry, innovation is rapidly progressing that within the near future a complete system or technology change can take place. Both industries steadily advance the performance of their products, meanwhile prices remain stable or even decrease. Both computers and cars are today available for everyone. Backbone of this development is the highly developed, standardized and well automated production technology, and the structured organization around individual firms or Original Equipment Manufacturers (OEMs). In construction, a similar development has yet to be triggered. The proposed systemic research in Innovation Deployment Strategies (IDS) shows that innovation, (innovation developed within the industry and transfer innovation), in the construction industry could be easily achieved by focusing on advanced and modular automation and robot technology, initially applied in the production process and later over the whole life cycle of the "construction product". Moreover, the proposed IDS research deals with advanced examples from the construction industry showing that process and technology innovations, as well as innovation methods themselves from other industries, could be applied to construction industry once a certain quality level in automation and robot technology deployed within the construction process, and finally within the product, is achieved. Within the IDS research, an interdisciplinary approach is followed where analysis of the structure of various industries, and enterprises within those industries, according to parameters such as organization, production technology, product performance, product structure and product renewal cycles, is performed. Production technology is a key factor for innovation in any industry. Once an advanced and modular production system is installed within an industry, a steady advance in production efficiency allows in general enhanced investment in R&D, new-product features and product performance. The manufacturing sector (automotive, aeronautical, electronics, etc.) for production, uses a set of similar or same technologies (primary technologies) in terms of control systems, logistics systems and automation. Therefore, companies that supply e.g. automation and robot technologies as i.e. Schunk, Motoman, Festo and Kuka, can develop highly advanced systems and later on distribute those technologies to various industries with only minor modifications (spreading thus the development cost of innovations over various industries). Similar strategy applies for construction industries product structure. Considering total building systems with its subsystems, we can easily deploy innovative technologies on a smaller scale just on a subsystem like facade, structure, services, appliances, materials resulting in incremental innovation contrary to frog leap innovation for total building product systems. This approach enables technologies and sub-components that are embedded in the final products of those sub system or component manufacturing industries. Sometimes advanced industries are even able to transfer process technologies and management strategies between each other.

1.1. State of the Art and Related Literature

Technology and Innovation Management in general are well deployed research fields. An outstanding collection of essays covering the whole field of innovation and innovation management can be found in (**Christensen et al., 2001**). Basic tools, strategies and different viewpoints on innovation for the integration of technological, market and organizational change are discussed by (**Tidd & Bessant, 2009**). Creativity strategies and techniques have been presented an analyzed by (**Hartschen et al., 2006)** and (**Backerra et al., 2002).** Modularity as the driver for systemic and controllable innovation has been analyzed by using the computer industry by (**Baldwin & Clark, 2000),** and (**Fujimoto, 1999)** by using the Toyota Production System (TPS) as examples of the phenomenon of evolutionary organizational change. Further concepts of creating innovation fast and efficient by opening up products and services to customer co-creation (**Reichwald & Piller, 2009**) have been developed and advanced by concepts about crowd sourcing (**Howe, 2009**) open innovation (**Chesbrough et al., 2008**) and open service innovation (**Chesbrough, 2011**). And the potential impact of spreading computer technology and social-networking systems on industry, research and society, have been analyzed as well (**Tapscott & Williams, 2010**). Furthermore, important research has been conducted by (**Cameroon & Green, 2009)** and **(Hayes, 2010)** which see innovation as a kind of change, which has to be managed carefully as multiple actors are involved. In general, the research field change management argues, that often human beings or organizations are reluctant to change as existing structures, power distribution and revenue streams are changed, and thus the real innovation is to convince actors and change their mindset by incentives. However, specific concepts, strategies and literature on the impact of change and the deployment on innovation in the construction industry are rare. Individual aspects of deploying innovation in construction industry as the concept of creating innovation by developing technologies for extreme environments (**Linner & Bock, 2010**) and by transferring technologies between ship building and construction industry (**Bock et al., 2011a**) have been explored by the authors. Additionally, the authors have analyzed the possibility of deploying advanced construction technology (**Bock et al., 2011b**) and product and service innovation within the construction industry (**Linner & Bock, 2012**). Although individual aspects of innovation in construction have been discussed a comprehensive framework that can be used for the systemic classification and generation of innovation in the construction industry has not been developed yet.

1.2. Research Question

The state of the art as well as the related literature reveals that construction specific change, technology and innovation generation methodology, and related management tools currently do not exist in a form that could support researchers and practitioners alike. Thus several research questions have been formulated by the authors. First, it had to be found out which innovation mechanisms are active within construction industry and how multiple mechanisms are interconnected and influence each other. Further, it had to be analyzed how production technology (which compared to other industries still quite labor is based in construction) influences the ability for innovation. Thus, the final research goal of the authors became the identification and analysis of construction specific innovation mechanisms, for the development of a comprehensive view or framework, which explains in a generalizing manner how innovation in construction can be created and deployed.

1.3. Research Method

To achieve their research goals the author's systematically went through 3 research steps. During step 1, the authors have analyzed multiple viewpoints and tools about innovation that have been developed in industry and innovation science (not construction specific, section 2). During step 2, authors have identified, analyzed and categorized innovation mechanisms relevant within construction industry (section 3 presents a summary of this study). Finally, in step 3, the authors have combined the knowledge gathered in both previous steps and advanced it in order to develop their own construction specific view for realizing innovation in construction (7-dimensional view, section 3). The paper describes all 3 research steps performed and presents the 7-DCI Diagram (Dimension Construction Innovation Diagram). Finally, the paper gives an outlook on future research activities.

2. TOOLS FOR INNOVATION CREATION

In general (not construction specific) innovation science various viewpoints have been established to look onto the potential innovation space and to define in which context the existing product, service or process and the intended change is situated. On basis of the literature review performed and outlined in the previous section, the authors have identified and analyzed a multitude of frameworks and views on innovations. The most important viewpoints the authors have found are: typological viewpoint, system viewpoint, process viewpoint and novelty level viewpoint (**Table 1**).

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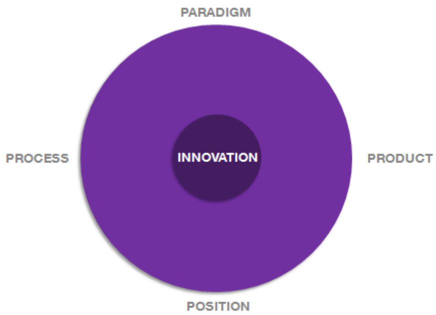
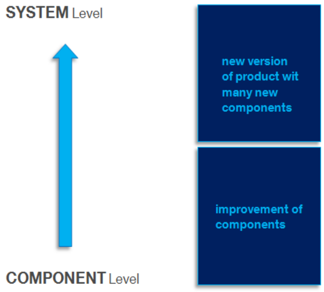
<tr><th>Typological Viewpoint</th><th>System Viewpoint</th></tr>
<tr><td>
</td><td>
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<tr><th>Process Viewpoint</th><th>Novelty Level Viewpoint</th></tr>
<tr><td colspan="2">Table 1: classification of innovation generation frameworks developed within general (not construction specific) innovation science</td></tr>
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Typological Viewpoint: The 4-P diagram states an example for a typological view on innovation. Innovations are classified and then arranged within the diagram. Four classes of innovation are defined within this diagram. “Paradigm” refers to innovations or major changes in underlying mental models or simply to mega trends as for example “E-Mobility”, “Ageing Society", “Energy Efficiency” or trends as for example the ongoing spread of small computation devices (“Ubiquitous Computing”).

System Viewpoint: Within a system viewpoint the product, the product/service system including the economic, managerial and social surrounding in which the item of consideration is situated is hierarchically structured into systems and (a multitude of) sub-systems. The sub-division into sub-systems can go down to the component or even mart or material level. In a further step, it is decided on which system levels the change or innovation is situated or has to be created e.g. on system level or only on a component level. A change on a system level is in most cases more complex as a multitude of sub-systems is affected. On the other hand, a change of a single component on a sub-system level might not necessarily affect the overall system or other components.

Process Viewpoint: The process viewpoint utilizes the fact that every product or service is relative to time and thus embedded in a process which often involves many actors (users, sellers, providers, producers, integrators, etc.) over time. An example for a creativity tool based on the process viewpoint is the Customer Value Matrix. Along the horizontal axis, the process in which the product is embedded is sequentially laid down. Along the vertical axis influential factors as for example risk, fun factor or added value are organized. All steps in the process are analyzed in relation to each influential factor.

Novelty Level Viewpoint: From the novelty level viewpoint, it is important to identify and if possible quantify the newness of a proposed innovation or change. Here the most common classification is the bipolar classification into incremental and disruptive innovation. Another classification system subdivides into routine innovation, improving innovation and radical innovation. A routine innovation is an innovation, for example, on the level of a daily work routine, an improving innovation might be the introduction of a new product or service to be delivered, and a radical innovation might be the change towards a completely new type of product (e.g. from looms to cars as done by Toyota).

When developing an innovation the mentioned viewpoints can be applied in parallel, and the potential innovation space can thus be identified and analyzed systematically. All views have their strengths and weaknesses. The system viewpoint, for example, can precisely define which parts of a system shall be affected by the change to be introduced. The viewpoint can identify mutable factors for change of even complementary innovations that would be necessary seen over the whole process chain. What all viewpoints have in common is that the levels or systems in which they classify and or subdivide are quite relative. This refers to the general problem that it is possible to qualify innovation relatively easy, but difficult to quantify it.

3. TYPES OF CONSTRUCTION INNOVATION (INNOVATION BY X)

The following chapter summarizes an analysis and categorization of innovation mechanisms in construction industry. The authors of this chapter have more than 25 years experience in the fields construction techniques, industrialized building production strategies, automation and robotics in construction. Thus, the authors have experience in what it means to work on the forefront of the technology and know what challenges and potentials are related to technological innovation. This experience helped the authors to identify, analyze and categorize innovation mechanisms in construction industry. According to the notion of DfX (Design for X), the authors suggest an IbX (Innovation by X) categorization that is open and can be extended by a new category (and thus X) once a new mechanism is identified.

3.1. Innovation by Production Technology (IbX)

One important innovation is the innovation by production technology, which is common in automotive industry. While the offered price for a car remains constant, the amount of features and technology increase. The competition between the production companies played an important role. So it is significant to optimize the production process and reduce production costs. The saved money will be invested for research, development, increasing technology and also for optimization of the production process. This enables the companies to offer a better featured car with constant price (**Figure 1**). Such a development can only be triggered by highly technological and automation based systems. Labor based production systems such as in conventional construction have, due to human nature, a natural limitation, whereas technology-based production systems virtually have no limitation.

3.2. Innovation by Modularity (IbM)

The modular structure of a product has an impact on all phases of its life cycle: development, planning, production, sales and use/customer. Thus, Modularity is important to manage the product and control its success over the whole life cycle. Open and changeable modular designs that allow the designers and engineers to improve or adapt a product continuously, are of relevance for controlling change and innovation processes. The modular structure can be set up in a way, which makes it possible that individual modules and components of a product can be exchanged by new or upgraded designs, or that new features can be added without making it necessary to abandon or re-engineer the whole product for a new-product series. Some companies as manufacturers of high-tech cars in Germany or housing prefabrication companies, do sometimes more than a hundred changes to a product per year. Sekisui Heim, a Japanese Prefab maker introduces about ten new housing models and about 400 modifications and improvements of existing solutions annually (**Furuse & Katano, 2006**) – change in that frequency can only be accomplished efficiently through advanced modularity based on OES principles. The modules that are not exchanged during OES improvement guarantee stable processes in logistics, production and sales.

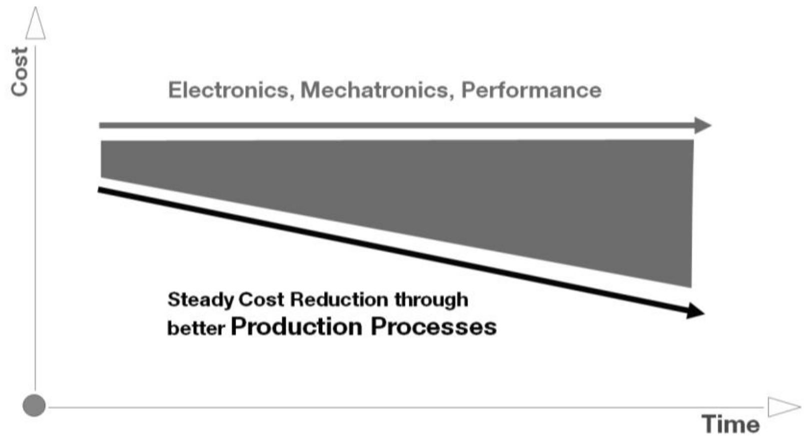

Figure 1: Product Performance in Automotive Industry

3.3. Innovation by Performance (IbP)

Today, the complexity of buildings continues to rise rapidly due to new paradigms as Ubiquitous Computing, the demand for energy efficiency, and emerging assistance technologies. Buildings become integrated with a multitude of new sub-systems and extend their performance to areas, which have formerly not been accounted as being part of construction and building industry, but now gradually merge with our built environment. With the integration of micro systems technology into buildings and due to the tendency towards enhanced user integration and a tendency towards mass customization (**Piller, 2006**), buildings become not only more intelligent, but they can be much more personalized to the inhabitants needs and could further serve as platforms for a multitude of continuous and commercial services. These changes could have a tremendous impact on the whole value chain and are likely to transform building structures, construction technologies and business models. For example, the production of a building in a controlled factory environment is highly demanded when buildings are equipped with advanced technologies as this type or production could control complexity, price and quality. This example shows clearly that innovation in one category could trigger or even necessitate innovation in another category. We will get back to this issue later on when we present our 7-DCI Diagram.

3.4. Innovation by Technology Transfer (IbT-fer)

As the name suggests, existing production systems will be used in another context. For example, in shipbuilding and aircraft construction, under slung cranes (roof) and rail systems (on ground) are used, which can be supportive in finishing buildings. A small quantity of companies developed and adapted such systems for the building industry. For example, an Airbus A380 is produced in an on-site construction and applied rail guided automation (**Figure 2a**). The Japanese company Kajima uses this system for its AMURAD (Automatic Up-Rising Construction by Advanced Technique, **Figure 2b**). The “field factory” is located on the ground floor as an on-site construction and a robotic system produced each floor from concrete components. Subsequently, all finished floors are pushed upwards by hydraulic press system, and then the next floor is also built on the ground level.

Figure 2a: Field factory with rail guided stationary production of airbus A380

Figure 2b: Field factory with rail guided stationary production of high-rise, Kajima’s AMURAD

3.5. Innovation by Transformation (IbT-form)

Innovation by Transformation is probably the most common way for innovation. An established technique will be transformed and adapted to increasing demands. In Japan, for example, it is common to build first the upper part of the building and start with the roof (**Figure 3a**). Under the roof, the rest of the house will be built on the ground level. For multi-storey buildings, each finished floor will be pushed upwards.

Figure 3a, 3b, 3c:The traditional way of building a house in Japan (Left: Roof built first) was transformed, refined and augmented by new technologies over time. Middle: Sekisui House, J-Up System. Right: Kajima’s AMURD for construction of high-rise buildings

Advantages are the whole construction process is roofed and construction materials needn’t lift up in the upper floors. It is therefore, no crane required. This traditional way of building a house in Japan was transformed, refined and augmented by new technologies over time. For example Sekisui House with its J-Up System (**Figure 3b**) and Kajima with the AMURAD for construction of high-rise buildings (**Figure 3c**) refined and transformed that approach.

3.6. Innovation by Overlay (IbO)

New innovations could also arise from designing a new production line manufactured with a consisting production plant. This consisting production plant often specifies the used material and influences the design of the developed product as well as existing technology and knowledge is applied to it. For example, after the Second World War the aircraft production in Wichita stagnated, so the company had to look for another production line.

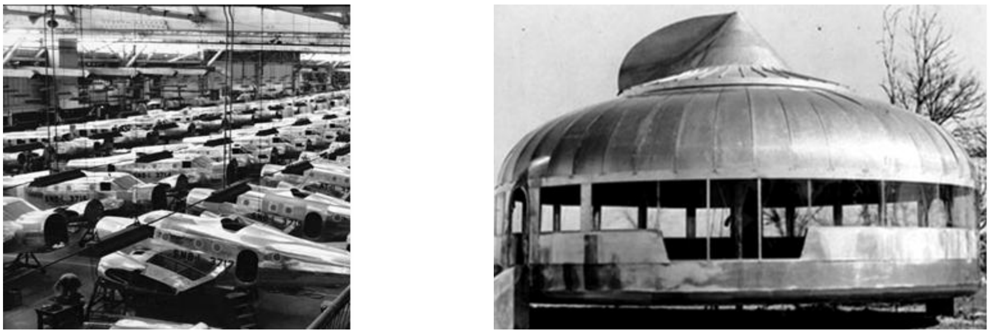

Figure 4a, 4b: Innovation by Overlay (IbO) of new processes on existing structures: After the Second World War Beetch Aircraft Company in Wichita had to look for another product to be sold and Richard Buckminster designed the famous Wichita House which could be produced by the existing aircraft production tools and processes. Left: Aircraft Production during War at Beetch. Right: Dymaxion Wichita House designed for aircraft like production.

Richard Buckminster designed the famous Wichita House (**Figure 4b**) which could be produced by the consisting aircraft production plant (**Figure 4a**) of the Beech Aircraft Corporation. This Wichita House evokes the shape and material of airplanes at that time. The idea behind this futuristic type of house is the mobility and optimization of it. The user can therefore move easily with the whole house because of its modularity. Another production line envisioned was the Dymaxion Car which looks a bit like an aircraft cabin. This phenomenon can also be found in the Messerschmitt Company. Messerschmitt was a German aircraft manufacturer and started after the Second World War with a new-designed car production line called Bubble and Cabin Cars.

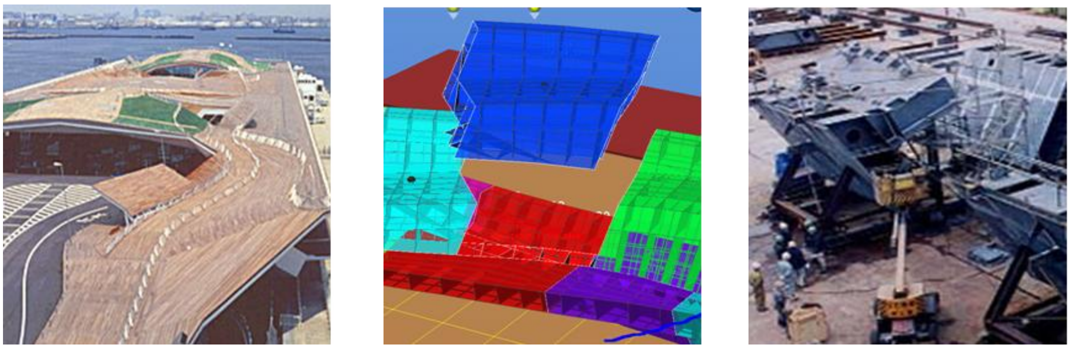

Figure 5a, 5b, 5c: Innovation by Overlay (IbO) of new processes on existing structures: Shimizu subcontracted the production of the complex structure of the Pier to a ship yard.

Another example for Innovation by an overlay is the Ōsanbashi Pier at the Port of Yokohama, located in Japan (**Figure 5a**). Originally, the Ōsanbashi was constructed between 1889 and

1896. The architecture firm Foreign Office Architects designed the reconstruction to meet modern demands, which finished 2002. For this construction, shipyards were utilized and the whole building was built like a huge ship (**Figure 5b**). The Company Shimizu Corporation executed the project but subcontracted the complex steel structure to be built by Kawasaki shipyard (**Figure 5c**). As this shows that existing production structures in – compared to construction- highly advanced and automated shipbuilding, we classify this example also as Innovation by an Overlay (IbO).

3.7 Innovation by Customer Co-Creation on product and service level (IbCo)

The requirements of a building increase constantly. To find out problems and customer needs, several companies perform individual tests. The marketing research divisions of Sekisui House, Daiwa House, Sekisui Heim and Toyota Home in general investigate the customer acceptance of the solution space in a six-month cycle. The results of these investigations are fed back into design development stage and continuously improve the products. Toyota Home, for example, focuses on designing smart houses and uses a modular system to construct these. This modular system is more adapted to customer needs and more flexible with its infill than usual houses. The Customization Culture "ringi seido" means that the decisions are non-hierarchical and informal made, so that information from customers and production are directly brought to management and product design (**Figure 6a**). To adapt more to the customer needs it is also necessary to involve services. Especially for older people it is more and more important to customize over inbuilt information platforms and networks by services like domestic aid or medical care. This includes also the integration of sensors for measuring vital signs or the connection to the PC and data platform (**Figure 6b and 6c**). This new services necessitate also new high-tech products able to act as service channel – and high tech construction products necessitate new ways of construction which are linked to quality and precision production and assembly. Later on in our 7-DCI Diagram we will outline that interconnectivity of innovation dimensions clearly.

Figure 6a, 6b, 6c: Innovation by Customer Co-Creation. Left: Japanese prefab companies invite customers to perform test to improve buildings in a co-creation process. Middle: Toto integrates a multitude of electronics, sensors and actuators into toilets in order to deliver additional functions and in the future even household related services (right).

4. REALIZING INNNOVATION IN CONSTRUCTION BY 7-DIMENSIONAL VIEW

Based on the research in tools and views developed and used in innovation science in general (section 2), and the analysis of the nature of innovation mechanisms in construction industry (section 3), we have started to develop our own comprehensive and construction specific view on innovation depicted by the 7-DCI Diagram (**Figure 7**). Through our background in industrialized architecture, automation and robotics in construction, we have always seen construction machinery and production technology as a key force for creating innovation. However, through our research in innovation methodology, we have learned that for the success of an innovation, often a multitude of changes and innovations subsequently or at once are necessary. Production technology can hardly be considered to be disconnected from materials, components, time, ecologic factors or product performance. In particular, this means, that production technology can cause, or force, change in all of those areas, and that i.e. a change on the material dimension or the ecologic dimension is linked to changes or innovations on the construction machinery/production level. Thus, for a practically oriented innovation deployment in construction, we have defined 7-dimensions as follows:

- **Dimension 1: Construction Materials:** referring to innovations in i.e., the development of ultra-strength concrete. Such a development might be linked to other innovations as for example robotics molding/material distribution and or a new design of components.
- **Dimension 2: Construction Machinery/Production Technology:** referring to incremental and disruptive innovations in the area of production technology used off-site or on-site. Improved robotic cranes or excavators might be seen as incremental short-term solutions. The use of exoskeletons, humanoid robots and automated construction sites as more radical and long-term innovations (disruptive innovations).
- **Dimension 3: Construction Components:** This dimension refers to the modular structure of a building. There are various ways to modularize construction products. Furthermore, components delivered to the site can introduce a low added value (low degree of complexity, no installations, etc. included) or high added value (high degree of complexity, equipped with finishing and installations. A quite innovative component states 3-dimensional units/space frames equipped with all finishing, installations and appliances. Those units are produced, for example, by Japanese companies as Sekisui Heim and Toyota Home fully on the production line.
- **Dimension 4: Construction Time:** This dimension refers to the time necessary for planning, set up of the site, construction and finishing. Changes in the timely setup or reductions of construction times are impossible to accomplish without changes in other dimensions. A very radical timely strategy (rapid construction) would necessitate radical solutions within almost all other levels.
- **Dimension 5: Construction Ecology:** This dimension refers to ecological factors related to the construction process itself or the construction product. In Japan, major construction firms are currently deploying automated deconstruction sites, which allow them to reduce construction time and recycle nearly all building materials. This states an example for innovation in this dimension, which is closely related to innovations in other dimensions.
- **Dimension 6: Construction Product Performance:** This dimension refers to innovations related to the construction products performance or services related to those products. Our environments become smarter and increasingly more sensors and actuators are embedded in our living environments enhancing performance and serviceability. However, new performance often demands also innovations, especially in the production and/or component dimension.
- **Dimension 7: Construction Management:** This dimension refers to innovation created on the managerial level. Management often can integrate innovations, while on the other hand it can be said that even small changes affect organization and thus the management dimension.

In addition to these seven dimensions of construction innovation, we have defined two key cross-section forces that can act within or across the described dimensions:

- **Force 1: Novelty Force:** This force refers to the newness of a change to be introduced - routine innovation, improvement innovation, radical innovation.
- **Force 2: System Division Force:** In section 2, we have introduced the system viewpoint on innovation. Our system division force refers to this viewpoint, but it also allows the possibility to apply the notion of systems and subsystems to all seven dimensions.

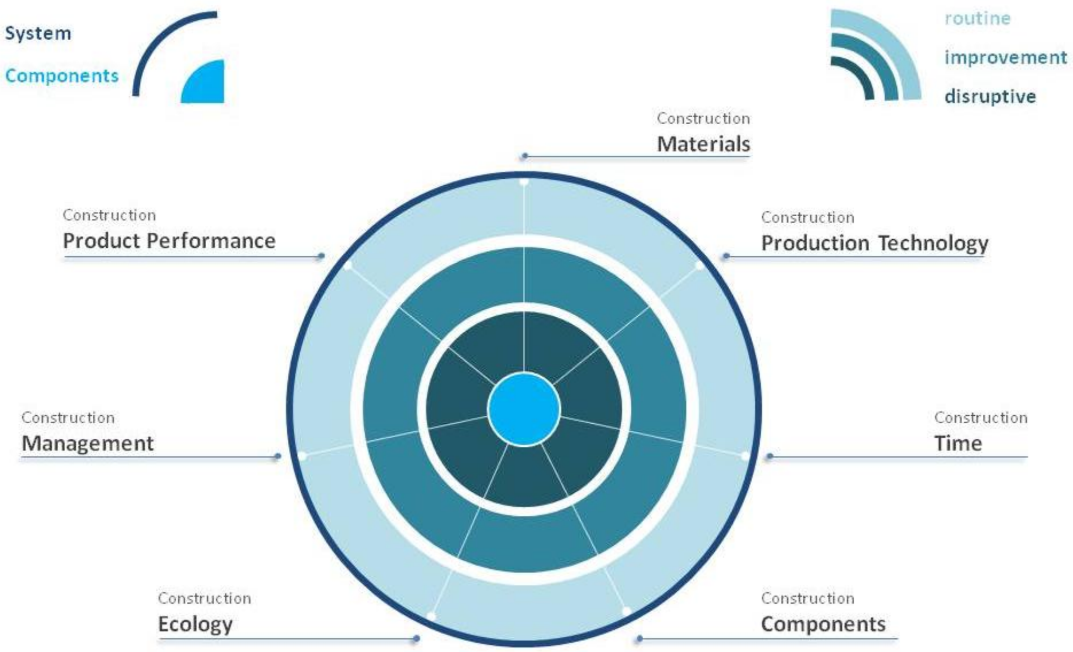

Figure 7: 7-DCI Diagram (Dimension Construction Innovation Diagram)

5. CONCLUSION AND FUTURE RESEARCH

We have presented the current state or our IDS research and summarized it in form of the 7-DCI Diagram. Aim of the research is to aid researchers and practitioners alike to identify and generate innovation mechanisms fast and efficiently. Future work includes the evaluation and refinement of the developed 7-DCI Diagram. To verify its practicability, functionality and architecture, we intend to conduct in depth case studies of innovative construction projects and try to verify if our 7-DCI Diagram is capable of explaining the innovation mechanisms in a sufficient way. Further, in order to test the practical applicability of our 7-DCI Diagram, we will apply it as the basis for concept, process and technology deployment within upcoming industry-university joint R&D projects. As part of our future work, we will investigate, if there are additional viewpoints or forces that have to be added to our framework.

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Figure 1, Figure 7: Chair for Building Realization and Robotics;

Figure 2a: Airbus, Toulouse; 2b: Chair for Building Realization and Robotics

Figure 3b: Sekisui House, Japan; 3c: Chair for Building Realization and Robotics

Figure 4a: Kansas Historical Society. http://www.kshs.org/,visited: 29.04.2012; 4b: Dymaxion House Prototype, Oldtwon Wichita. http://www.oldtownwichita.com/, visited: 29.04.2012

Figure 5a, 5b, 5c: Pictures by Dr. Yusuke Yamazaki, Shimizu Institute of Technology

Figure 6a: Sekisui Heim; 6b: Chair for Building Realization and Robotics; 6c: Sophia mit P.S.