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Innovative, Dynamic and Collaborative Technologies for Integral Design

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This position paper introduces the mission of the Section Design and Construction Processes at the Faculty of Civil Engineering and Geosciences (CEG), Delft University of Technology. Our mission is the scientific and scholarly exploration, research (basic and applied scientific research) and the development of useful and innovative tools necessary for the creation of sustainable construction with the aim of scientific management and advanced education in this area of high industrial importance and recognition. The instruments consist of new theories, methods and techniques such as ICT-based solutions as well as tools for innovation in building and construction. The prime objective of the section is to cultivate strong ties between his scientific research and industrial innovation in an ideal position for significant contributions to science, education and social services. The research agenda of the section responds to the enormous challenges of the changing building and construction (BC) industry as a whole in the coming decades. This contribution is reflected in the research program 'Living Building Concept' (LBC) that strongly encompasses issues in the BC industry such sustainability (cradle-to-cradle), lifecycle management, collaboration and innovative technologies. This approach advocates starting from certainty and what the BC industry knows rather than with uncertainty towards certainty. LBC suggestion is to assemble bottom-up solutions and allow for changes during an evolutionary process.

Keywords: Living Building Concept, building and construction, industrial innovation, sustainability, cradle-to-cradle, lifecycle management, collaboration, innovative technologies

1 Introduction

The mission of the Section Design and Construction Processes of the Department of 'Design and Construction', faculty of Civil Engineering and Geosciences (CiTG), Delft University of Technology is the scientific and scholarly observation, exploration and inquiry (fundamental and applied scientific research) as well as the development of useful and innovative technologies necessary for the realization of a transition in the building and construction industry with the aim to establish scientific leadership and advanced teaching in this field of high industrial importance and recognition. Innovative technologies are all existing, adapted, improved and emerging theories, methods and techniques including ICT-based solutions and tools for innovation in building and construction. These technologies are driven by innovative processes. The Section cultivates strong ties between its scientific research agenda and industrial innovation which places it in an ideal position to make significant contributions to science, education and society. The research agenda of the Section responds to the enormous challenges that the BC industry as a whole will face over the next decennia.

The research contribution of the Section is spearheaded by the 'Living Building Concept' that is based on the accepted reality that the environment of construction activities changes at a much faster pace than the changes of the constructed object itself. The Living Building Concept provides the core of a theoretical framework wherein a new 'value' concept plays an equally significant role as the cost of construction activities. As the 'world' changes rapidly in terms

of user demands, climate, regulations, owners, economy and technology, it becomes an absolute necessity that a building and construction activity is able to adapt itself to changing conditions and circumstances in order to:

- Stay '*fit-for-purpose*' in a functional way
- Stay aesthetically '*up-to-date*'
- Be provided with '*state-of-the-art*' technology

This requires a dynamic coupling between the '*living construction*' and the '*living world'*, whereas in the present situation the living world is caught into a building and construction activity that is obsolete at least before the end of its economical lifespan. The life of a building and construction is dynamic and hence should be adaptable. In this sense the building and construction is and can behave like a *living* object.

2 The Living Building Concept

The *'Living Building Concept'* considers an evolutionary process for human-made systems in particular for construction activities (similarities can be drawn with Darwinism and theories of evolution). Therefore the building and construction is considered as a system composed by a large number of elements, components and sub systems with associated and different characteristics, properties and lifespan. In this regard the lifespan of the whole system is not interesting. Building and construction activities are interventions. Interventions at the highest scale level result in completely new building and construction activities whereas interventions at the lowest scale levels are maintenance activities. Interventions are conservation, repair, replacement, adoption, modification and addition. For each intervention the increase in value and the increase of cost as consequence of the intervention over the design lifespan of the intervened object should be determined. If the differential value is larger than the differential costs (measured with respect to the situation before the intervention and expressed in percentages, the intervention can be taken place if the costs will stay within the budget.

The design lifespan (characteristic lifespan is perhaps a better term) is not the normally accepted economical lifespan. Instead the design lifespan of an object is determined by taking into account recycling of elements with a lifespan shorter than the design lifespan and reuse of elements with a lifespan longer than the design lifespan.

As a result, value and cost are managed and controlled in a dynamic way during any time or stage in the lifespan of a building and construction activity. Broad adoption of this approach will have widespread consequences for the relationships between stakeholders, the methods of tendering, the assignment of tasks as well as the sharing of responsibilities and risks. The '*Living Building Concept*' provides a consistent and coherent image of the manner in which stakeholders can collaborate in the new building and construction paradigm in order to increase the benefit for the client and the profit for the supplier. According to the Section's vision this concept presents an urgently needed replacement of the current unsatisfactory construction paradigm that is conducive to construction activities being carried out with yesterday's techniques and today's viewpoints for the benefit of tomorrow's people, thus causing these works to become outdated quickly.

3 The building and construction industry in transition

The building and construction (BC) industry is suffering from its fragmented and multi-cultural organisation. Especially in large-scale one-of-a-kind building and construction projects, costs of failure form a substantial part of the total project costs, certainly if costs of failure is seen in its broadest meaning - exceeding the common failure costs due to building and construction errors, time delays and requirement changes - to include those cost elements that are outside the responsibility of the project partners, i.e. inefficiency due to communication problems, or aspects outside the scope of the project, i.e. costs by others due to traffic jams, health problems and accidents, environmental pollution, juridical hassling, and client dissatisfaction. Until recently there was no great incentive for the industry to change. Clients reluctantly paid the 'additional' costs and if necessary the juridical costs and competitors were more or less in the same league. Slowly, but surely, the BC industry is changing with many clients no longer accepting that they are not in control, and not accepting costs of failure (both in the process and in the resulting artefacts). Increasing pressure to shorten lead times and deliver value for money is the general result. In addition, society and its governmental representatives increase their demands on safety, environment, energy, sustainability and such, resulting in even more regulations, more red tape and more information to process and communicate.

The building and construction industry is trying to respond to the changing requirements. Several ways to increase its competitiveness are being developed. Organisational approaches result in new contract types like Design-Build-Operate. Car manufacturer's experiences in Lean Production result in Lean Construction. In addition, the application of Information and Communication Technology (ICT) has stimulated several new approaches. Computers and computer networks are masters in information processing and communication. Costs of failure somehow always result from miscommunication. No wonder that ICT is seen as one of the cornerstones of the solution. The changing trend of the BC industry is shown in Table 1 that is the chief motivation for the emergence of the '*Living Building Concept*' as a basis for innovative technologies that will facilitate the required paradigm shift.

Table 1 Changing trends of the building and construction industry

From Segmented Design	**To Integral Design**
Short time profit	*Value-oriented service market*
Fragmented supply chains	*Integrated value chains*
Involvement of stakeholders (direct actors)	*Involvement of all stakeholders*
Focus on the control of costs	*Focus on the production of benefits*
Risk management prior to the process	*Risk management during process*
Price competition and fixed specifications	*Competition on innovative concepts*
Reactive and opportunistic behaviour	*Proactive and learning behaviour*

The living building concept requires a totally different approach with respect to relations between stakeholders, organisation and legal matters. In fact, the top-down organised artisanal tailor made approach will be replaced by market driven, bottom up organised integrated supply chains which develop product-

families and product-modules with a large number of variables. These supply chains are able to aggregate these product-families into a client specific solution. Figure 1 sketches the paradigm shift from the traditional structure and culture of the traditional building and construction sector into the market driven structure and culture of the *Living Building Concept*.

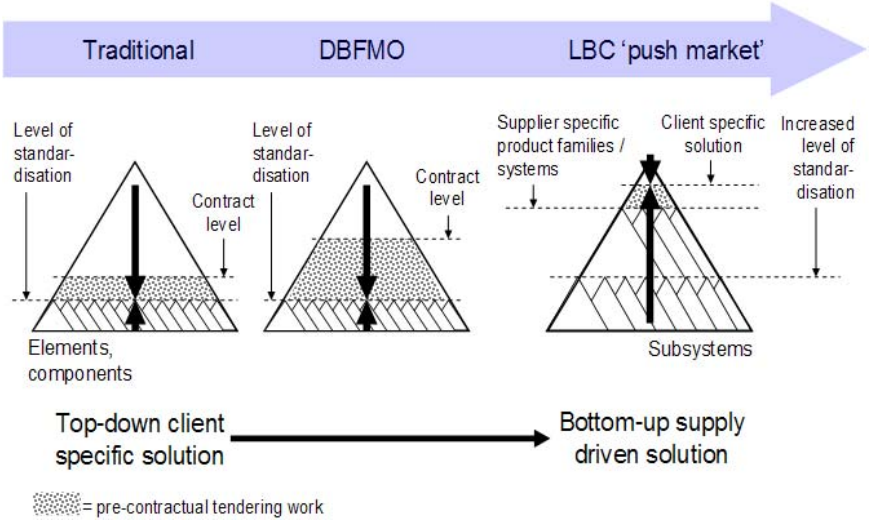

Figure 1 The transition from demand-driven supply towards supply-driven demand construction industry

The main condition for the LBC is that the difference between the real world and the virtual world will disappear. In this regard the quality of the virtual world should increase to a level that it can become a true representation of the real world when it is possible to run real simulations of living buildings and constructions. A dynamic way of working with value and costs as variables in time requires a multi dimensional modelling of construction activities. Not only length, width, height and time are the relevant dimensions but also all characteristics and properties should be included in the virtual reality of a construction activity. Examples are aesthetic value (space, luxury, connection and safety), functional value (capacities and availability), technical value (energy consumption, emissions, climate and reliability) and costs (initial, maintenance and operation).

4 Intended paradigm shift for building and construction

The major thrust for the intended paradigm shift is the generation of models, systems and instruments that adequately address value, performance, added-value and cost-benefit issues of building and construction activities and support the structural and cultural transition from a demand-driven supply industry towards a supply-driven demand industry. Although the building and construction is readily becoming a service oriented industry, it has systemic problems in making this transition smoothly. This manifests itself in lacking support for the complex management of the multi stakeholder objectives and failure to provide the essential cost/value perspectives for these stakeholders. Litigation, adversarial partnerships, undervaluing of the skill base and unfair practices are the sad results of this. It is clear that the current approaches in the construction sector, dominated

by the notion of cost only are in need of urgent replacement. The research challenge is to create better methods (based on sound theories), (ICT-based) tools and (ICT-supported) processes to execute a service industry that is adapted to the needs of the 21st century. In short we can observe the '*Living Building Concept*' as a framework for the mission of the section. On the one hand LBC defines the theoretical framework of research components. On the other hand LBC is an open and flexible concept for the added-value of a dynamic building and construction life cycle, allowing a broader definition of research components of the section. The two research areas of the section are on the one hand closely connected with each other but on the other hand are also clearly separated. This is sketched in Figure 2. The research area of Design Methodology deals with 1) the complicated top-down process to be conducted by the Client /Owner in order to define his solution space, 2) the aggregation work of the supplier in order to provide an adequate solution for the Client composed by an unique combination of supplier specific standard products and 3) the living contracts (both partnering as well as outsourcing) between demanding and supplying parties.

LBC also provides adequate freedom for Process Modelling as the second area of research of the section that regards formulating a bottom-up approach directed at the development of elements, products (Dynamic BIM) and standards (existing and emerged standards including IFC). In this regard LBC is in fact a business model that follows a system and modelling approach for introducing smart construction that benefits from ideas such as Dynamic BIM/IFC, product modelling, etc.

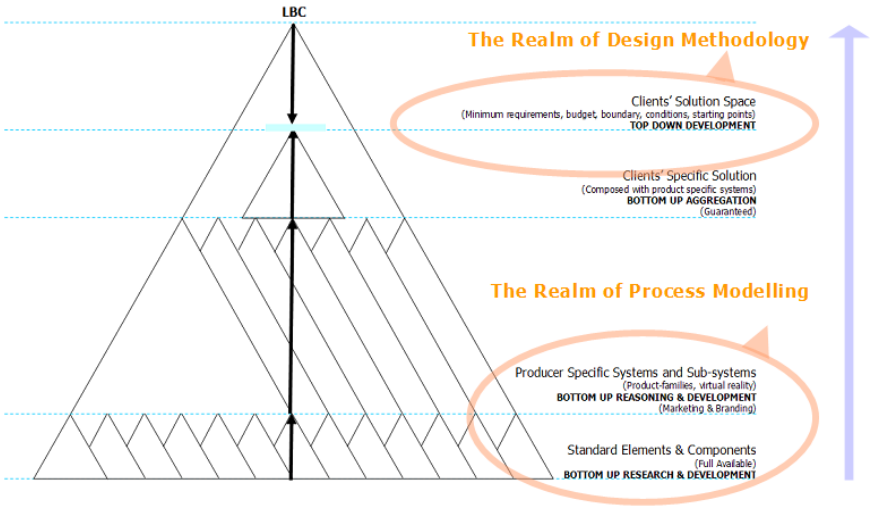

Figure 2 Areas of research, development and education of the section Design and Construction Processes

In this regard innovative technologies play a crucial role in the realization of both research realms of the section. Presently solutions based on innovative technologies are manifest at the project level, when an expert consortium positions itself within the same market and they are not properly organised. As a consequence meaningful electronic communication (between systems) is difficult or it does not exist, while that is crucial for the management of complex processes. By means of correct use of LBC components, it is possible to employ

correct systems and protocols. This is one the most important aspects of LBC that is beneficial for the stakeholders and subsequently for the improvement of building and construction process, allowing for future adaptabilities. The realm of process modelling adheres to a bottom-up approach that allows a broader implementation of LBC components, within the framework of building and construction information model (conceptual, theoretical and implementation aspects of a Dynamic BIM). In this regard the research of the section plays a much broader role in building and construction processes (dynamic and static supply-demand chains) and its implications for the BC industry (Dynamic BIM). The chief goal of research is to realize the concept of 'value' of building and construction in the light of LBC components as basis for further research and development.

The general framework for the mission of the section is provided by the realm of the Design Methodology but the realm of Process Modelling is required in order to complete the LBC view mentioned above. The latter enables the section to execute the *Living Building Concept* into the development of new (some ICT-based) process-driven technologies required for aligning and realizing partnerships in the BC industry. This translates into research that targets novel (based on innovative systems, technologies, models, simulation, etc.) project models, cost and value management instruments and process performance metrics that are rooted in system theoretic research, benchmarked in simulations and applied in industrial applications. These will arguably lead to better process models controls, knowledge and supply chain controls, new partnership models etc. implemented through industry ownership of innovation that originates in academia.

The section Design and Construction Processes embarks on the realization of this vision through scholarly research and development of advanced (ICT-based) project models and establishment of an advanced curriculum that exposes students to new (ICT-based) systems and models. The core focus of the research is on the project and process scale of building and construction projects. The linkages with the larger societal, organization and market dimensions will be pursued through affiliations and multi-disciplinary projects with national, European and international research groups and bodies.

The Section's research program makes a key contribution to the linkage of the scientific knowledge cycle and business innovation cycle that will enable the section to play a central role in the realization of the section's ambition to become a world player in formulating theories about life cycle valuing, life cycle costing in design and construction and innovative enabling technologies (including Dynamic BIM). In this regard the section is in a position to make a unique contribution to the building and construction sector as a whole.

As mentioned earlier the central theme of the section (reflected in its research and education programme) is building and construction processes involving systematic inquiries into the management of projects, technologies and people, driven by multi-faceted performance, value, and cost metrics. The intended research targets existing, adapted, improved and emerging innovative theories, methods and techniques driven by innovative technologies, based on tools and value systems that can be applied to the innovation of building and construction projects. Research methods will have their roots in two fundamental sciences: 1) the hard engineering sciences focusing on the performance of constructed sys-

tems and their underlying hard technologies; and 2) the softer management sciences focusing on the performance of humans, teams and their management and management support systems.

The amalgamation of the two foci is an essential prerequisite to study the holistic performance and innovation capacity of building and construction processes. It expresses the essential role that new innovative technologies play in the system to system, human-to-human and inter-organizational transactions at the interfaces between design programming, design, engineering, building and construction, etc. Innovation at these interfaces will be a leading thrust of the research agenda of the section. Learning from the past failures, the research will prepare a major shift in the way innovative instruments and solutions (Dynamic BIM and ICT-based technologies) are introduced into the industry.

Employed research methods for developing innovative technologies are expected to be a mix of advanced process and product modelling and simulation, multi-aspect building performance simulation, uncertainty and risk analysis, team performance and management metrics, performance and value-based building methodologies, collaboration and dialogue management theories, and industrial benchmarking of new methods and theories.

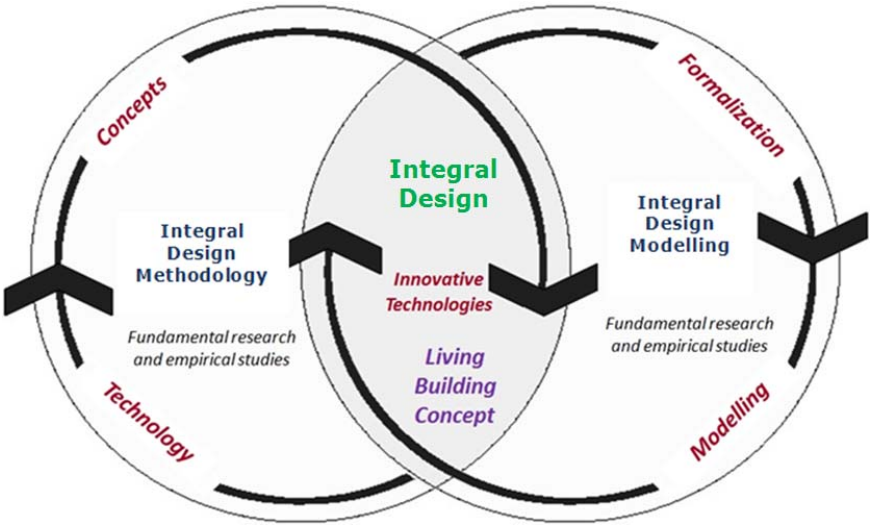

Figure 3 Complementary research and education foci of the section

5 Prerequisites for paradigm shift

The core of research and education activities of the section is directed towards top-down and bottom-up modelling of building and construction activities and their parts. This is primarily about the integral modelling of processes and products including all relevant technical and economical specifications and characteristics of building and construction activities. This will lead to building and construction activities being offered as 'state-of-the-art, up-to-date, fit-for-purpose and sustainable. These are relevant elements in building and construction process innovation and implementation of complex building and construction activities.

Complementary research and education foci of the section distinctively emphasize the mission of the section that is reflected in the approach and the accent

given to fundamental research and empirical studies of design and building processes during the entire building and construction lifecycle that are clearly defined in the research programme of the section The '*Living Building Concept*' (conceptualization / formalization and modelling / instrumentation, taking top-down and bottom-up approaches regarding the scope of research and dealing with LBC components).
Currently the use of ICT is very limited. Every professional uses computers, but no electronic meaningful (semantic) communication is possible and ICT is not used on the project level. Currently communicating in and over large-scale construction projects is still done by traditional means: drawings, fax, mobiles and meetings.
With the advent of the next generation XML-based Internet the BC industry can be provided with a new Communication Technology that is applicable for meaningful electronic communication 1) between humans, 2) between humans and computer applications, and 3) between computer applications. Only if humans (parties involved in a project) and computers share a common ontology of building and construction terms and definitions, then electronic communication becomes feasible.
It is of great importance for the BC industry and the society as a whole that the current unsatisfying paper-based building and construction documents be replaced by electronic documents that can be exchanged over the Internet. The development of intelligent construction documents is an interesting subject for research.

6 Education for building and construction paradigm shift

Compared to the pace of innovation in other industries, the building and construction (BC) industry is rather traditional. In the last two decades however, increasing market and society demands are forcing the BC industry to change from a traditional industry branch, characterised by fragmentation and bewilderment into an innovative industry branch, characterised by co-operation, efficiency and competitiveness. In order to cope with the increasing demands, the BC industry has to adopt new techniques and technologies in the field of management, organisation, manufacturing and innovative technologies. In this respect, a number of trends are noticeable including a number of reform programmes that have been initiated by national governments to facilitate this change such as the Rethinking programme in the United Kingdom and the PSIBouw programme in the Netherlands as well as the European Open Building Manufacturing initiative. The new paradigm together with other proposed reformations place heavy demands on the competence of the BC industry and its employees - a new type of competence that is not the same as it used to be. These types of changes require a change in ways of "deciding, doing, acting and responding" within the industry, i.e. it requires a change in the needs of skills and knowledge of (future) employees working in today's BC industry. These inevitable changes ask for custom tailored learning and training solutions that are time and place independent. This ambition requires clear understanding of on the following concepts:

- Learning is the act of acquiring an active knowledge of technical issues related to the changing BC skills
- Training is the act of acquiring performances that are required for the appli-

cation of new BC skills

- Blended learning and training policy refers to the necessity of simultaneous availability of a blend of various modes of learning and training for new BC skills as well as favourable working environments and working cultures for BC disciplines

7 Research Themes

The methodological character the program of the section implies that there is an almost one-to-one relation between its research themes and the application areas. One research theme may be relevant for multiple application areas, and, vice versa, an industrial application of the construction may draw upon knowledge generated in more than one research theme. Nonetheless, the scope of the program will impose limits to the issues where the program will focus, in the order of priority, on the following main research themes:

1. Integral Design Issues (in combination with Dynamic BIM environments)
2. Management Issues (including Contracting, Risk Management, Procurement, PPP and Assent Management; also in combination with Dynamic BIM environments)
3. Built Environment Issues (including Sustainability, Risks, Safety, Security, Quality Assurance, Standardization; in combination with Dynamic BIM environments)

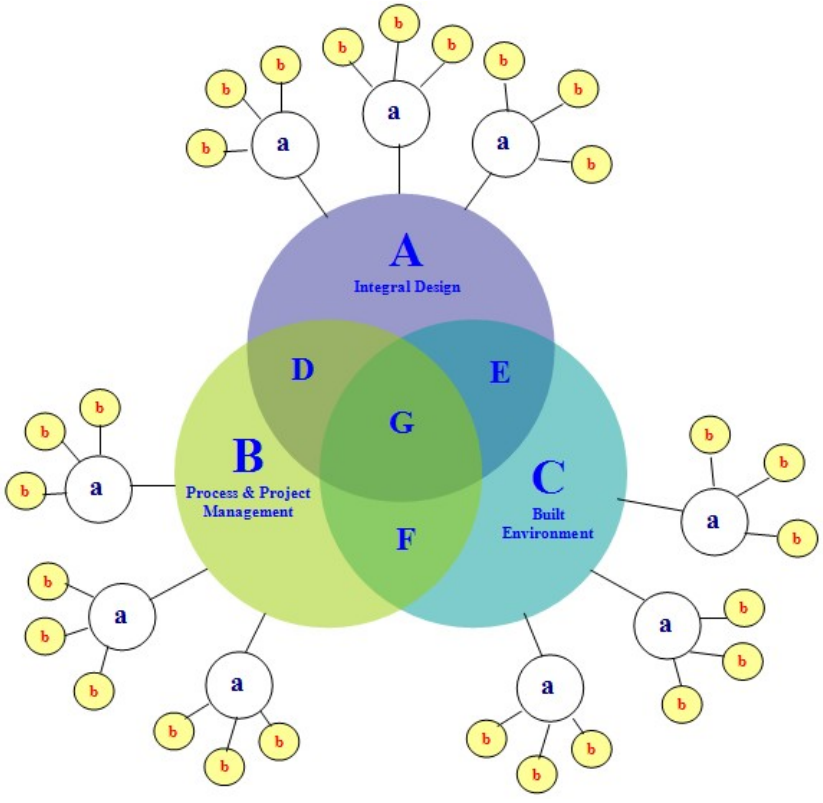

Figure 4 LBC implementation of Integral Design on different fields

Table 2 The requirements of each research theme at each level

Levels / Research Themes	MACRO	MESO	MICRO
Integral Design	- Generating views on master planning of cities - Urban development issues - National Policy for integral design - Land Use Planning - Innovation techniques - Dynamic BIM - GIS applications - Standardization of integral design	- Lenience management - Design requirements for living buildings, offices and structures - Dynamic BIM	- Interactions with components - Industrialization of components - Tools for a standard integral design - Dynamic BIM - The production process and the material properties
Process and Project Management	- National regulations for contracting - EMVI - Culture of consulting companies or contractors - Uniform information management - Dynamic BIM	- Involvement and the role of public / private parties and contracting / financing - Managing large scale projects - Strategic management - Systems engineering - Financial management - Risk management - Stakeholder management - Scope management - Tactical management - Chain management - Dynamic BIM	- Utilization of processes - Standardization of processes - Dynamic BIM
The Built Environment	- Policy for environmental integrated design issues - Changing climate changes - Maintenance policy - Safety Regulations - Environmental issues - Sustainability issues - Dynamic BIM	- Regulations for environmental integrated design issues - Construction relevant design - Maintenance techniques - Safety integrated Urban Plans - Production management - Dynamic BIM	- Practical measures for environmental integrated design issues - Practical measures for construction design - Maintenance tools - Industrialized construction methods - Dynamic BIM

Research themes can also be defined in a combination of these fields and in overlapping areas of the above mentioned main issues (Figure 4). The focus will be on the main research themes at different levels, namely macro level (urban level), meso level (area level) and micro level (building (component) level)). In

spite of the combination of research themes, every research theme still provides different requirements at different levels, since the impact of each level has a unique feature. The question is what the characteristics of each level are. Following is a short description of the required research vision at each level.

- Macro level issues: At this level, we bring the general societal trends into consideration, especially in large scale construction projects. Making a policy planning for instance the land use planning on a national scale or urban development into perspectives of political economy, economic transformation, long wave rhythms, and world or global systems, can be the major starting points of research themes.
- Meso level issues: At this intermediate level, attention will be paid to the roles and behaviours of various institutions in both private and public sectors. We need to examine how various institutions have shaped urban or infrastructure or urban development trajectory and thus result in different urban (development) forms.
- Micro level issues: This is the individual level process using a behavioural approach from theories and concepts of the life cycle of a single construction to major tools which can be used directly by the construction sector.

The requirements of each research theme per levels are defined once both the research themes and the scale levels are described. This is described in Table 2. It should be noticed that combination of both research themes and levels and combination within the research themes and levels are possible.

7 Conclusions

The mission of the section Design and Construction Processes at the Faculty of Civil Engineering and Geosciences (CEG), Delft University of technology is the scientific and scholarly exploration, research (basic and applied scientific research) and the development of useful and innovative tools necessary for the creation of sustainable construction with the aim of scientific management and advanced education in this area of high industrial importance and recognition to settle. Innovative technologies consist of new theories, methods and techniques such as ICT-based solutions as well as tools for innovation in building and construction processes. The prime objective of the section is to cultivate strong ties between his scientific research and industrial innovation in an ideal position for significant contributions to science, education and social services. The research agenda of the section responds to the enormous challenges of the BC industry as a whole in the coming decades. This contribution is reflected in the research program '*Living Building Concept'* (LBC):

- LBC aims at stopping the waste in building and construction by reducing the difference between long and short lifespan in terms of technical and economic life of building and construction elements.
- LBC looks to life-cycle of components and elements of buildings and constructions instead of the life cycles of buildings and constructions as a whole. The LBC does not look to the whole but to the parts. LBC also looks to the market for their components.
- LBC brings a number of components and elements flow around the buildings and constructions. The suggestion is to carry out complex building and construction works with the most advanced equipment while considering the reuse

of materials, elements and components.

- LBC creates a whole new market that ultimately results in a built environment with a lot more architecture, quality and quantity than now (This is replaced by the momentum of high quality and reuse). This is possible because the floors, windows, roofs, beams, walls, doors, kitchens, bathrooms, stairs, equipment, lifts, etc. (if properly treated) are much more common in building and construction than we think. That means a good deal less waste and more (de) mounting and reuse in building and construction.
- LBC expects the impact of this stream of parts to the whole. Interventions are justified by calculating both the total 'value added and removed' and the 'added and removed' from the total costs over the planned lifespan of the operation. This is the only way that ''*cradle-2-cradle*'' can be applied to the building and construction industry. It is both effective and efficient to (re)use parts designed for sustainability that is environmentally responsible, socially acceptable and economically viable.
- LBC requires a different structure and culture in building and construction. No more top down chains fragmented but integrated chains dealing with a complex *bottom-up aggregation* based on a theoretical approach with unique structures are composed of capacity new and existing elements while maintaining all relationships.

8 Discussion

In the current situation everyone has made mistakes. This is because of the evil system in the building and construction industry that works from uncertain to certain. They try to capture details while they do not know anything about the outcome in details. They call this Estimation. When they reach bricks and screws of the project after 10 to 15 years, then they are surprised by the realization that everything is different from what they were originally planned. A government wants a subway line. Then engineers come to help. Everything is closely planned because governments distrust the builders. The contractor is squeezed into giving the lowest price, because the plan must be sold politically. The fact is that the more the client specifies the project, the more the client is responsible if anything goes wrong. This calls for another approach to the procurement of major building and construction projects. It comes down to a few selected players to develop a plan. This is called an *integral tendering*. Pay two competing contractors to come up with their own solutions. Let the contractors think of what they must actually build. They will surely do not come up with fancy and complicated things, because they also think much clearer of their obligations (including financial) and responsibilities (including technical). With this approach one builds from much more certainty to uncertainty. The contractor just starts with what he knows and he certainly can. This is thinking great but doing little. Governments have a tendency to employ loads of independent consultants to advise them on all matter during the whole process of a building and construction project. Many of them have an interest in making things as complicated as possible. They build nothing. So it is wise to leave all the work to the market, then, things will turn right. Making a Deep Wall is a very simple construction that any mediocre builder can do it. What should concern us more is that there is no need or place for top-down thinking. The contractor of a failed tram tunnel in The Hague an-

nounced that he would have never chosen for the tunnelling technique that was used. Nevertheless he was forced by the client to employ the technique with disastrous consequences.

The contribution towards an innovative new approach for building and construction is reflected in the research program '*Living Building Concept*' (LBC) that strongly encompasses issues in the BC industry such as sustainability (cradle-to-cradle), lifecycle management, collaboration and innovative technologies. This approach advocates starting from certainty and what the BC industry knows rather than with uncertainty towards certainty. LBC suggestion is to assemble bottom-up solutions and allow for changes during an evolutionary process.

The *Living Building concept* presented in this position paper represents an abstract, sociological, or even philosophical view on building and built services. The term "*Living Building*" refers to the dynamic approach to built services, the construction project, and the life cycle. In this concept the basic economic parameters value, price and costs are defined and interlinked on a high abstraction level representing the performance of the built service. The basic premise is the dynamic character of the connection between value and costs, price and performance: no prescription of output against a fixed price, but rather defining a dynamic connection between performance and price. The *Living Building Concept* has been acknowledged by PSIBouw as a promising concept for the desired transition of the Dutch construction industry.

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