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Value Creation through Integrated Design-Build Management

-an ICT-driven Strategy for Design, Project Planning and Constructability

0.1 Title leaf

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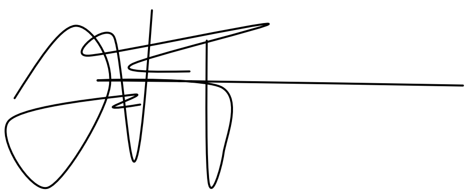
0.2 Preface and acknowledgements

This report is the final documentation of the author's 4th-term project at Aalborg University, Dept. of Civil Engineering and concludes the Master of Science and Technology (Civil Engineering degree) in Building Informatics, *Cand. Scient. Techn. Bygningsinformatik*. The master's degree spans four academic terms, of which the final semester's work is conducted between Sept. 1st 2012 and Jan. 10th 2013.

The work is to be carried out as prescribed in the educational decree of Oct, 21st, 2010 -as put forth, recognized and accredited by the Danish Ministry of Education. The project is to assume an adequately broad perspective, theoretically and practically, to ascertain its conclusions and recommendations. The report[1] is directed at practitioners of the building industry that are assumed to hold knowledge of the processes, products and performances of our built environment, and have a sincere interest in the future of the industry and its methodologies. Moreover, it is specifically directed at a leading-edge contracting firm in Denmark, which was kind enough to integrate me into their everyday organizational routine, that I get a chance to obtain the insider's view of things. To the collaborating company I offer my sincere appreciation, especially the people of the BIM-department, who have been most forthcoming towards me.

In the process, the following people have been instrumental in my academic progression and growth, for which I am grateful and offer my thanks: Kjeld Svidt, associate professor at the University of Aalborg, Maria Thygesen, scientific assistant, and of course my professional adviser. Thanks to Brad Phillips and Volker Mueller for their help, and everyone interviewed in the process.

Enjoy,



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[1] *This assignment has been carried out by the aforementioned student at the University of Aalborg, Joakim Lockert. The assignment/report expresses solely the sentiment of this student, and therefore, does not necessarily reflect the notions or attitudes held by the University of Aalborg, or the collaborating company. Any copying, reproduction or use is allowed only with proper referencing ensured.*

0.3 Abstract

This study deals with the management of integrated Design-Build procurement, through which a single contracting firm designs and builds. Central to this study was to uncover the streams of information in dispatch and reception, acting on a variety of processes, to evaluate the consequences of inadequate information exchanges. Sharing information, risks and rewards evenhandedly is a prerequisite of a fully integrated practice, which includes drawing on the relevant proficiencies of every stakeholder involved and as such, input is continuously put forward by stakeholders. Consequently, an effort to analyze the potential reduction of perceived impediments, that is; attenuating time and cost in a design process, does not inevitably need specific stages of design development as focal points, or any specific procurement model for that matter. Indeed, no distinct organizational structure is needed (Reed, 2011). This rationale led to examining three representative case studies, comprising design, execution and the planning of future projects, to analyze the process of moving from approximations to progressively more externalized (Nonaka & Konno, 1998), precise information for constructability, and ultimately to value creation, in the form of savings. Through intermediate, successive conclusions on the optimization of knowledge creation and communication in the design and specification stages, a strategy for the betterment of overall performance through integrated Design-Build management was formulated. Early stages of building projects pertain to schemes and concepts formed on the basis of clients' and end-users' needs, to which the hard-data proposals of the building trades correspond, ensuring constructability through planning and design. Because integrated practice commits holistically to the entire timescale of projects, the localization and identification of impediments to value creation, to improve project outcomes, is a principal necessity.

Keywords: *Integrated Design-Build management, Value creation, Architectural design, Engineering design Contracting, Procurement, Constructability, Project planning, IPD, BIM, VDC.*

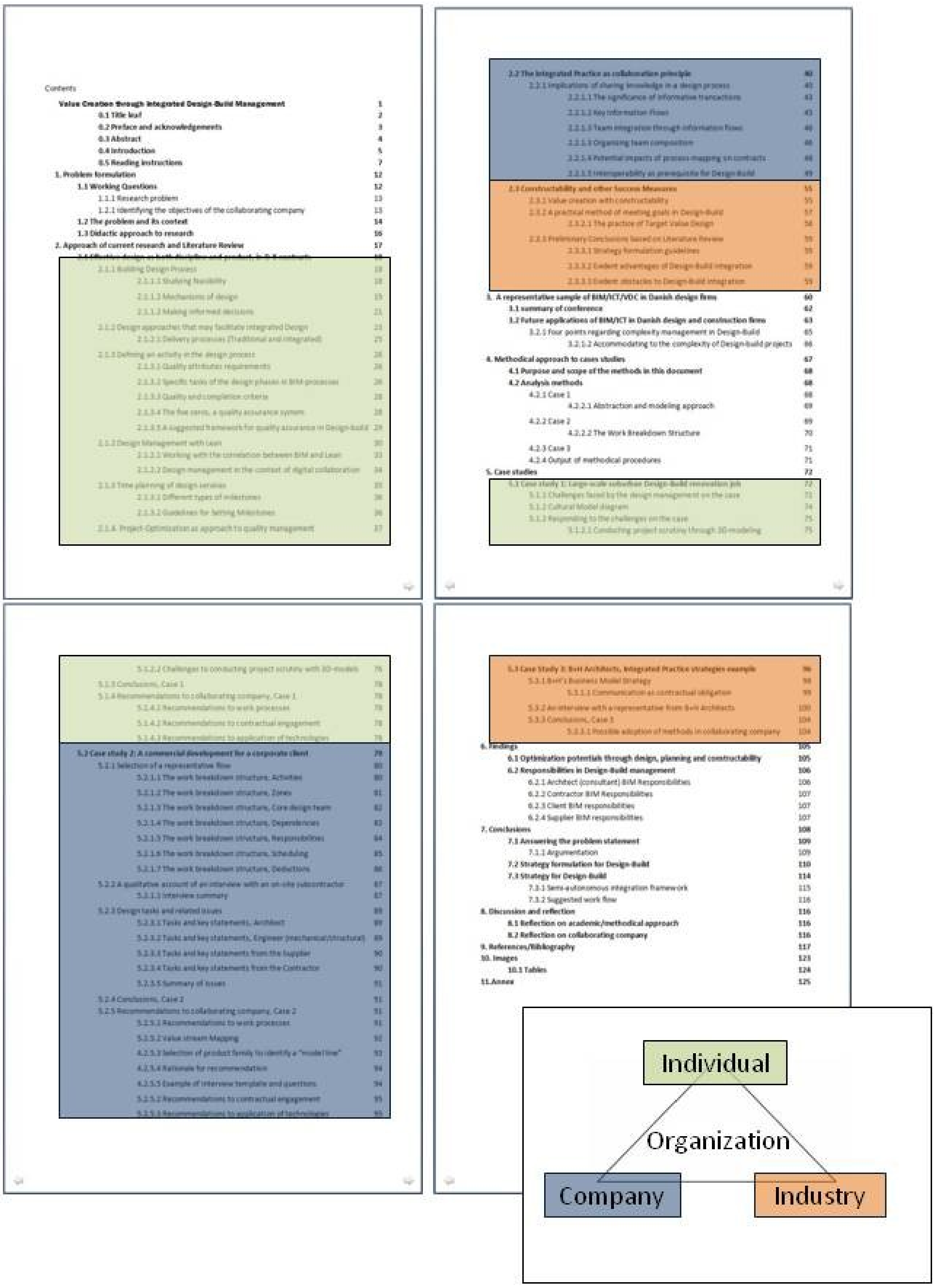
0.4 Introduction

Construction is a multifaceted and dynamic industry, with notable fluctuations in market confidence rates and investments. Also, in one week last year, (36/2012), 60% of public tenders were Design-Build procurements (CRMByggefakta, 2012), this indication being but one week's worth of figures. This type of arrangement seems to be gaining pervasiveness –and with it, more issues of the same nature that this report has set out to address: The optimization efforts that continuously drive the building sciences, as well as the industry's professionals to continuously perform better. Design management may be defined as accurately satisfying a set of requirements, subject to constraints; its primary engagement being production support. That is, the purposeful arrangement of parts or details to advance a real-world project for functionality, profit and knowledge. This is relevant to Design-Build management, by virtue of that link between the conceptual and the real, in the constructability of a proposal. The identification of obstacles to constructability is pivotal to a productive design process and this validation of a facility's design is one of the most persuasive arguments for both Design-Build, as well as recent broad-scale implementation of digital modeling in the building industry. It is a well-established notion that the earlier design changes are implemented, the cheaper those changes will be (NIST, 2004). This phase/cost correlation shows us that to influence a project, one must address issues at the earliest time possible. However, an organizational paradigm that warrants a division of stakeholders into phases cannot coincide with Design-Build management, since no universal sequence of stages and as a result, no "siloing" of stakeholders, is practically applicable to this form of contracting. Ideally, in Design-Build management, the total expenditure of a project is consolidated at the time of commitment to the contract (Boligministeriet, 1993). This fixed price reduces financial risks for a client (McMullan, 2012), as a contractor held legally responsible for exceeding the project budget will have a clear incentive to stay within that fixed price (Morgenson & Harvey, 2002). The contractor is thus commissioned to become an agent of systematic mitigation and alleviation of any kind of risk which could potentially alter the expected outcome and value of a given planned economic/industrial action.

These efforts to duteously retain value at a fixed cost, induced by the contractors' apparent reluctance to change the probability of achieving business objectives, could have side effects. Namely, this capacity of implied restriction, which is authorized by financial risks, *may* ultimately inhibit emergent, iterative processes in the pre-programming/brief, schematic programming and concept design “phases” of architectural and technical design. This would be the one place where the Design-Build arrangement could become adversarial: the different trades *will* prioritize differently (Broyles, 2011). However, economic restriction is also a design constraint, which influences the spatial configuration and functional/mechanical performance of the built facility. This is a central point to integrated practice: the project organization can incorporate costs as a factor in waste reduction. The contractor now arguably possesses the capacity to assume tactical control of the early phases of projects, through the Design-Build methodology. Costs do not need to follow design in inter/multidisciplinary projects, if the contractor proactively contributes to the solutions. Return on investments could be increased by a co-evolving design, price and production system, with repeatedly scrutinizing estimates, creating a real-time design consensus involving clients, end-users, designers and the contractor. In that context, this report sets out to find/conceive a framework to make projects as worthwhile for the project team and the client as possible.

There are many incentives to integrate Design-Build practice (NIBS_WBDG, 2012). It is apparent that some optimization barriers do exist nonetheless; else there would be no room for optimization on building projects, which arguably, there is. As stated, the sequence of phases is theoretically absent in Design-Build arrangements, with no stage exclusively representing its conventional “phase-bound” stakeholders, and therefore specific milestones like the submittal of proposals (for building permit, for example) become less central to evaluating projects. This seems elementary to the nature of planning and managing services, since allocating time to activities and foreseeing milestones are some of the basic tasks carried out by design and construction managers. The optimization barriers will exist in the processes and exchanges, and be monitored in the work performed. As such, they must be confined to either technology use or interactions/communications. These two constituents, technology and the “human aspect“, are very closely connected factors, however. People routinely interact through computers, to mention but one thing, the tools and the collaboration becoming co-dependent, co-evolving phenomena. To simplify a process implies fewer parts, fewer steps and minimizing co-dependence, through transparency (Lindhard, 2011). The uncertainty-management facilitated by comprehensible, standardized processes means reducing costs, time and communication barriers.

0.5 Reading instructions



The first chapter of the literature review (theoretical part) illuminates case 1, the second chapter of the literature review: case 2, the third chapter of the literature review: case 3.

The preliminary conclusions of the review and the findings of the cases inform the findings of the study as a whole, upon which conclusions are made.

Contents

1. Problem formulation

The following working-questions compose the formulation of an academically operative problem. The questions lead up to the formulation itself, which is not based on the analyses of a specific case, as no *one* case has, at the present, been seen fit to research all of the prevalent issues of the Design-Build contractual arrangements. Rather, it is the provisional result of current discourse on general concerns regarding this type of arrangement, such as the lack of competitive bidding and perceived inflexibility of the contractual relationships (Leontiadis, 2002), as well as a continuous dialogue with the collaborating company.

These working questions provide guideposts to more specifically determine the problem at hand:

1.1 Working Questions

The first relevant questions are associated with the organization at large: *"What are the prevailing guidelines for the work done by consultants from different disciplines (in-house or otherwise), provided such guidelines exist, and what is the exact approach to transforming input to output? (Transformation-Flow-Value)".*

Additionally, the question; *"How does a contracting firm establish the most effective possible form of collaborative work-integration, in its design process?"* can be asked, to uncover how possible guidelines may be established, if no protocol is in place on a clearly outlined project. Subsequently, these three rhetorical questions are posed to emphasize the convergence between the miscellaneous interests and stakeholders on a Design-Build assignment:

- "How are redesigns and iterations in a design process mandated, (which may take more time than expected), if the contractor is subject to a fixed-price contract?"
- "How are performance criteria (manifest in construction knowledge and construction methods), balanced with economic goals and client demands?"
- "How can the need for prognoses and planning, as well as any unpredictable variations in these processes, reduced by way of standardized/simplified processes?"

With these questions as the mainspring of the research, the one key inquiry must be to assess how valid and relevant contributed information can be integrated into the conceptual planning and technical design of a Design-Build project, to input comprehensive instructions and systematically communicate trade- and contract-specific demands, within the current/recurring constraints of building practice, commonly recognized as time, cost and quality. These integration efforts are to comply with industry standards, customs and formal mandates from the management of the company in question.

1.1.1 Research problem

The task of this research, thusly, must be to ask and respond to the following formulation:

"How can a contracting firm accomplish its overall project objectives as rewardingly as possible, within Design-Build contract arrangements, on the basis of its design and specification procedures?"

1.2.1 Identifying the objectives of the collaborating company

Value creation through integrated Design-Build management is a concept that may be viewed from many angles. The angle assumed here focuses on the problem; *how to accomplish objectives rewardingly*, from the point of the company with which this assignment has been carried out. A Copenhagen based contractor, they have bid on many large scale projects through the years and have become a "household name" in the industry.

It is held implicit in this work that the objective of the collaborating company must be *to improve continuously*. This presents support for regarding the productivity and profit of the collaborating company as the main drivers for its existence, and the spine of this academic report. Hence, value creation means for the company to save money. Savings are the root of economic growth and capital formation, through interests and capital investment (Schwabe, 2012). Value is defined as the relative assigned worth of something, created by innovating a new way to reach a current need: (a safer car, a better house).

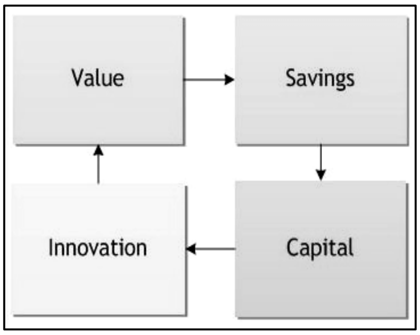


Figure 1, Value creation mechanisms (Schwabe, 2012)

1.2 The problem and its context

The company was founded in 2001, in a merger between two contracting firms. It has roughly 5000 employees, its 2011 turnover was 9.3 billion DKK, its profit before tax of -335 million DKK and its tax margin was -3.6%, cf. the graphs in figure 1.

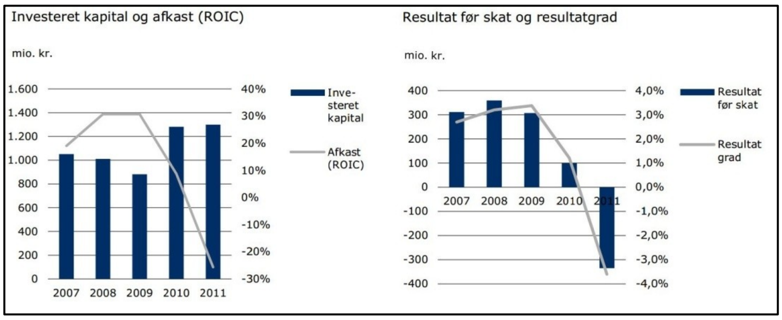


Figure 2, Return on Invested capital and Result with tax margin for 2011, (courtesy of Collaborating company, 2012)

The graphs are not regulated to specifically show Design-Build contracts, and therefore show overall key performance indicators. Hence, we cannot infer that the Design-Build arrangements perform better or worse than the overall company, since no figures have been published, to the knowledge of the author, that indicate how this specific form of contracting is faring in the company, as compared to conventional tendering. Two assumptions can be made, however, even without knowing any exact figures: 1) Any business wants to improve its performance, and 2) that problems at hand are not exclusively caused by a company itself, but owe much to the general oscillations in a macro-economic interplay of factors, cf. figure 2:

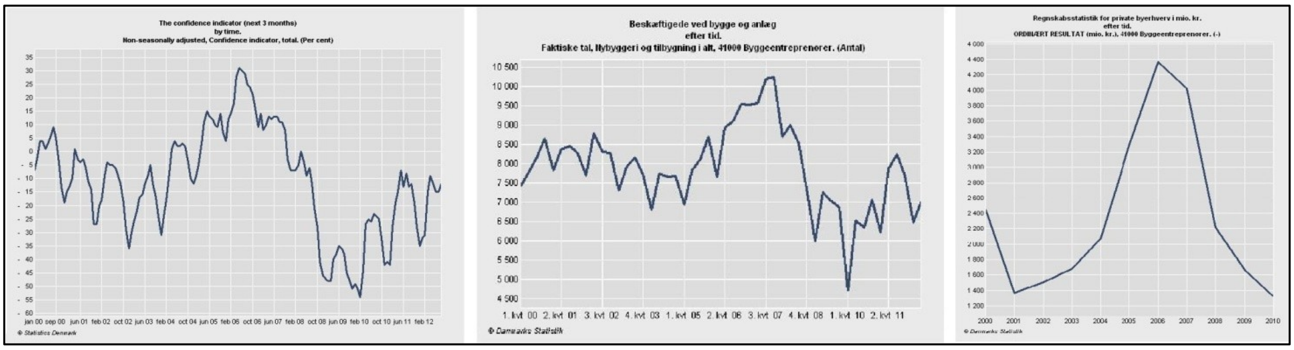


Figure 3, Graphs showing investor confidence, number of employees in the Danish building sector and annual profits for contracting firms in Denmark. All graphs span 10 yrs. (DanmarksStatistik, 2012)

In this research, the work flows and methods of the project participants assigned to Design-Build projects in the collaborating company are presumed to follow certain principles of behavior. The presumptions made about the company's work will include: That the honest performance of all involved stakeholders on projects is ensured; that the lack of incentives to sub-optimize, due to the contractual basis of the collective nature of Design-Build projects prevails; that the lack of needing to mitigate the needs of every contributor to promote betterment for their respective organization holds true and -lastly, that the sanctioning of the transparency and uninhibited flow of information, which "true BIM" advocates and systematizes, is recognized. One key driver of these points, as perceived by this author, is the standardization of methods and procedures, driven by the demand of the profession at large, and its clients. This must be implemented serving the company's needs, as well as through regulation and planning, without significantly restricting the creative process of the project. This perspective might arguably seem idealistic, but having a look at figure 3, showing the percentage-wise implementation of BIM with UK contracting firms in 2011, may prove otherwise. The UK is one country that Denmark is certainly comparable to, in terms of technological advancement and, moreover, the collaborating company can be considered a large and progressive firm in its industry context.

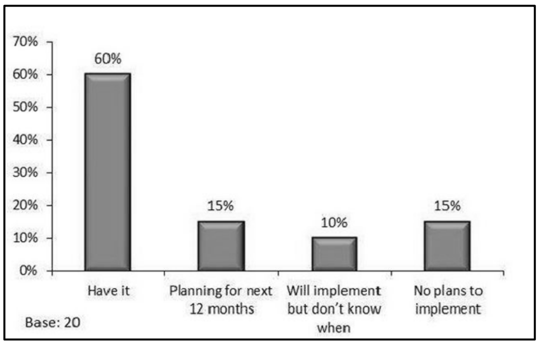


Figure 4, Adoption of BIM -A Research Report, Implementation of BIM with UK contractors, (Ashworth, 2011)

The point being made here is that this report is not about implementation efforts of Building Information Modeling, as many academic and professional efforts have (and are) focused on this, as per the rich literature on the subject. It is therefore *presumed* that the company is beyond struggling against technological advances, and that it is willing, as an entity, to harness the potential value of ICT, cf. its BIM-department. On the basis of this cursory analysis of the circumstances of the organization and because of an explicit directive to use information modeling/virtual design & construction in design and engineering services on every contract by 2013, the company can be said to be a "technologically receptive environment".

1.3 Didactic approach to research

Monetary value is the obvious observable metric to support the formulation of a strategy to obtain accomplishment and reward, for a specific type of contracting. Money spent versus money earned. This research “takes a step back from this”, figuratively speaking: Instead of analyzing an abstraction of value, as represented by money, we can set out to analyze the factors that only later will become evident in a company’s financial accounting: whether a working environment facilitates productivity, a digital model facilitates communication or a practical problem can be directly alleviated by the human agents affected by it. This perspective arguably validates qualitative research directions.

The research project is “confirmatory” (Jaeger & Halliday, 1998), in the sense that an *a priori* hypothesis is applied, in the assumption that the company in question *wants* to improve its performance and that, regrettably, the global/geopolitical debt crisis of recent years calls for doing just that. This statement is based on the results observed in the graphs showing tax margin and turnover, chapter 1.2. The confirmatory process, as opposed to an exploratory one, is chosen to reduce the probability of non-significant results at the conclusion of the work.

The academic methods practiced over the course of this project are:

- Literature review
- Longitudinal case studies
- Ethnographic studies
- Structured interviews
- Semi-structured interviews

One reason for this flexible research design is that some of the variables (in the form of empirical data and relevant literature), that are to be represented in this report are not quantitatively measurable, such as culture. The longitudinal case studies and ethnographic studies, conducted on two separate cases, are analyzed through methods acquired from Information Systems literature, professional/organizational practice and academic schooling, over a limited time scale as imposed by the duration of one academic term.

2. Approach of current research and Literature Review

Since the self-appointed assignment of this thesis project is to identify improvement potentials in the organization (as stated in chapter 2), a literature study is undertaken to assess what has already been published on the means to improve a design process. As this is an identification of the potential improvements to the design and specification processes, it follows that it must be a prospective, forwardly reckoning analysis, a contribution to the strategies of the company. The following headlines are devised on the basis of tension between the capacities of human agents at different hierarchical levels of the work, as described in the strategic literature (Crossan, Fry, & Killing, 2002): The “strategic triangle”, figure 5, indicates the correlating relationships between the various levels of organizational practice, and how these are related to the performance of an organization since they must be aligned, on their respective scales, to operate and create value.

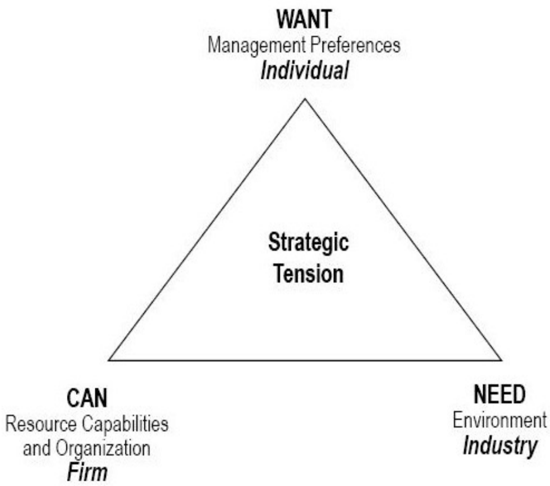


Figure 5, The Strategic Triangle, (Crossan, Fry, & Killing, 2002)

- Effective design as both discipline and product, in Design-Build arrangements: *the “Want”, on an individual level*.
- The integrated practice as collaboration principle: *the “Can”, on a firm level.*
- Constructability and supplementary Success Measures in construction: *the Need, on an industry level.*

Each of the above headlines form the basis of the literature review, so in order to clarify the criteria upon which the specific works of literature have been selected for this specific thesis project; the works emphasize this relationship between the ambitions of the company and its hierarchy. The cases in this report will be analyzed to also reflect the various scales at which the angles of the strategic triangle interrelate (individual/firm/industry).

2.1 Effective design as both discipline and product, in D-B contracts

This chapter is about the individual consultant/designer/planner in the organization and his/hers incentives to perform better, in projects and processes, with the design stages as primary process.

2.1.1 Building Design Process

The term building design process is defined in this report as pertaining to: the client's concept of a project, the feasibility studies undertaken by him/her or consultants, the programming and schematic phases through which a set of realistic demands are posed, and finally how those demands are satisfied by way of informed problem solving. The notion of being informed means to understand the facts of a situation and to show knowledge, to facilitate decision making, judgment or choice. This is central to design activities in architecture and construction.

2.1.1.1 Studying feasibility

No project ever embarked on has been initiated to lessen the value of a space. A feasibility study is an appraisal of a client's demands, with regards to any prioritized parameter of a building's performance. An activity sequence in the feasibility studies can be diagrammatically shown, see below (Driscoll, 2010). In the ideation stage, the programming of a space can support the process by cross-referencing room configuration with the client's stated demands, through visual aids like spreadsheets or sketches/3D. Alternatively, it is one initial step of the subsequent design process.

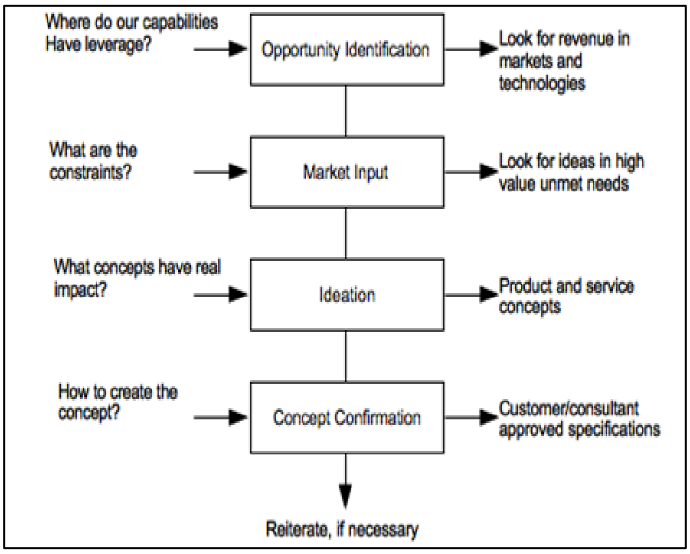


Figure 6, Business case and feasibility study approach, (Driscoll, 2010)

"Market", in this instance, should be understood as externalities, as in the conditions that may have consequences for the project. It is implied that early phases of AEC projects deal with needs and demands to value that will be representative of contemporary society, be it commercial gain, the environment or aesthetics. At a supply-chain level, it can be said that integrated practice is already in effect.

In stating ideas and concepts, a client inadvertently poses specific requirements to a built facility.

2.1.1.2 Mechanisms of design

Where the feasibility study is really a requirements stage, in which a requirement-BIM can be made through spatial programming, also pointing to the contractual relationships on a case (Christoffersen, 2012), the design phase can be said to "import" these requirements as basis for a design-BIM. A design phase is the first part of a project that addresses *how exactly* the requirements to the project are to be met. Whereas the interplay of quality, time and cost is the fundamental dynamic in construction management, the early design process has similar catalysts, expressed in different terms. The site, program and budget are the basic constraints of most building design processes (Box, 2007). Subsequently, the process of problem solving/design can be graphically formulated as shown in the diagram below (Laseau, 1980) (Pugh, 1990) (Jones, 1970):

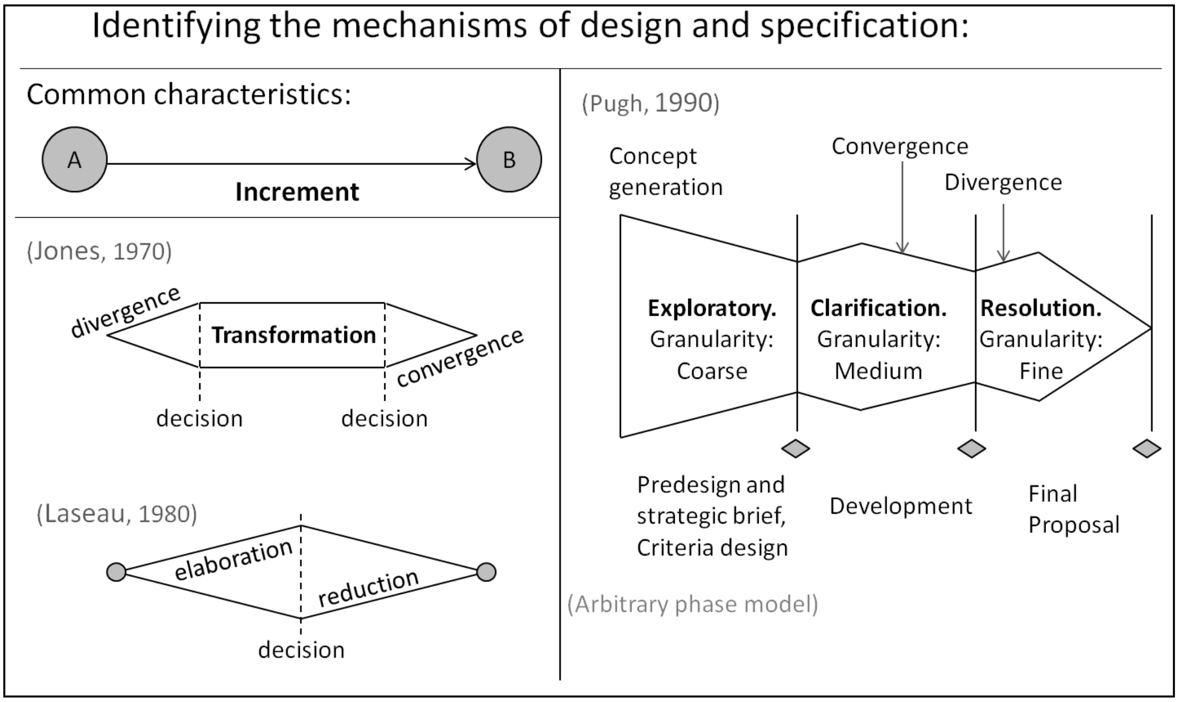


Figure 7, Mechanisms of Design, by author

The researchers in question all emphasize the elaboration and reduction (funneling) as the prime motor in design tasks. The concept of *granularity* is addressed later in this report.

Design tasks start with how designers/consultants interact with their modeling tools to meet demands, specifications and constraints. Five ways to interact with building models have been formulated as imperative commands (Smith, 2008):

- Insert

- Extract
- Update
- Modify
- Observe

The term *Modification* is the least clarified notion of Smith's five interactions and is elaborated thusly:

The technique is formalized in the following checklist, in question form (Osborn, 1957):

- Other uses?
- Adapt?
- Magnify/minify?
- Substitute?
- Rearrange?
- Reverse?
- Combine?

In combination, this hierarchical setup can be used to address design problems in the technical specification of a building, for example by way of a VDC/Concurrent engineering/BIM approach, as Smith's and Osborne's techniques show ways to interact with a virtual building which do not dictate any specific approach, since the two-way effect of the tool and the work of the practitioner is the only thing specified. There are no roles or tools assigned to these concepts/activities.

Walter Gropius (1883-1969) is quoted as having said: *"Architecture begins where engineering ends".* This notion can be said to be obsolete, as made irrelevant by multi-party contracting and an integrated Design-Build method. Nowadays we could say: *"Successful projects begin where misinformation ends"*. Many different phase models exist, but is the term "architectural/engineering design" really this ambiguous?

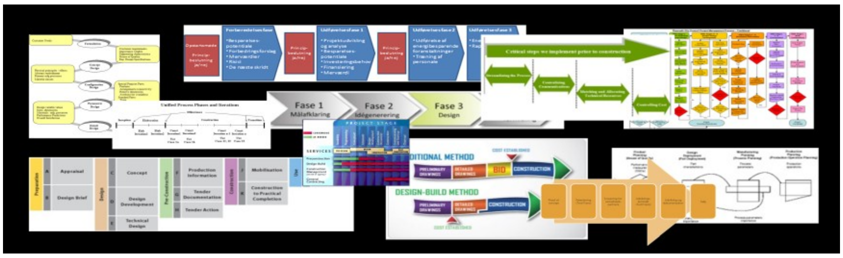


Figure 8, Various design phase models graphically conveyed, by author

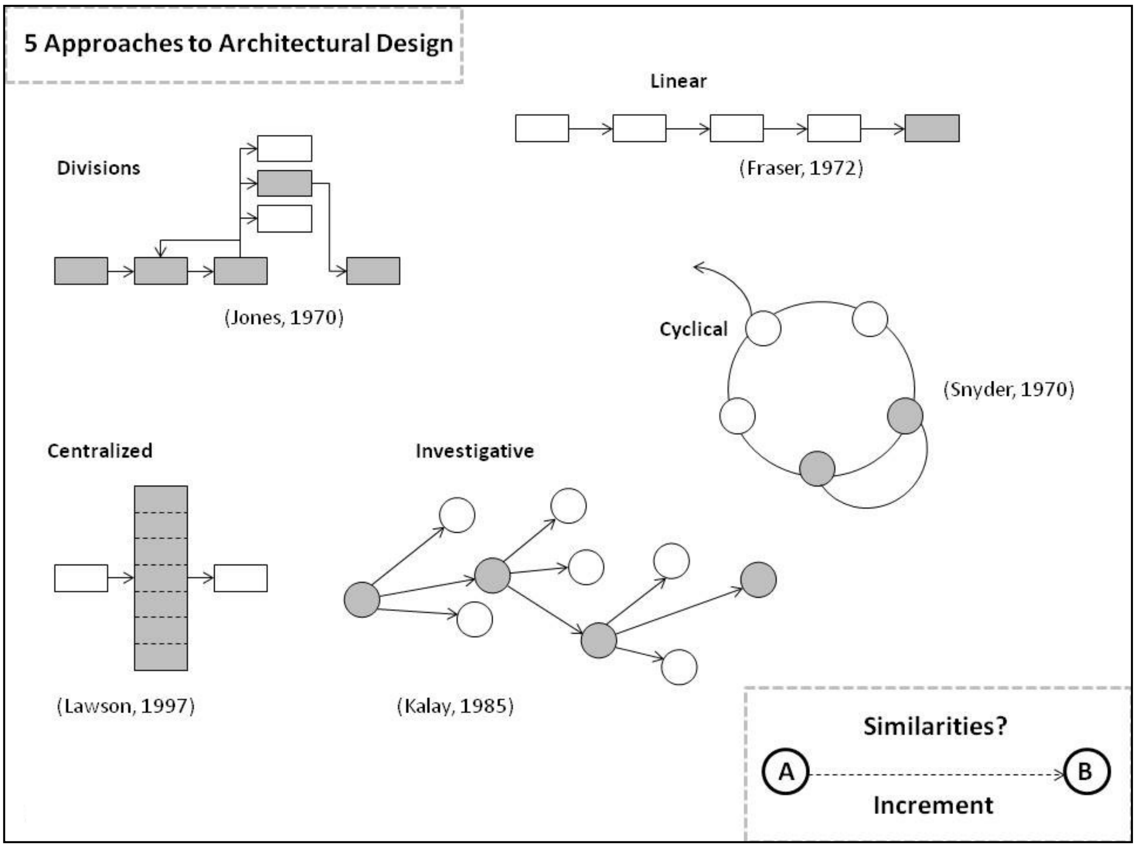


Figure 9, Five approaches to architectural design, by author, adapted from (Muhammad, 2009)

The diagram above shows five different ways to show decision making in incremental steps, where a step can be thought of as a combination of Smith's and Osborne's techniques to interact with a design medium through some form of technology, to make a choice about a building's design. Once again, we see that a process goes from start-to-end through a series of discriminatory choices, driven by the constraint of satisfying the needs and demands to the value of the project.

2.1.1.2 Making Informed decisions

In the context of AEC, "technology" refers both to the implementation and use of tools by which to bring about a product (modeling and simulation), as well as the stationary product itself, the built facility. In the design of a built facility, we therefore use tools to facilitate the two-way effect of the tool and the work of the practitioner. Here, "practitioner" refers to the designer who makes relevant choices. As this document addresses a contractor's perspective, however, the programming and conceptual phases can be said to be implied in the work, due to the earlier temporal/evolutionary state in the increment of the design. Therefore, a list acquired from the collaborating company’s on-line knowledge system, of the demands to designers/ technical designers/ consultants, is included here:

“Engineers and designers (technical assistants included) perform the design and specification of their respective activities in coordination with design-management. Engineers and designers working in the collaborating company can be expected to:

- *Know the Project Basis (formalized document) for their own tasks, as well as interfaces with other designers/consultants.*
- *Actively take part in the communication pertaining to following up and managing changes in project material, as pertaining to the Project Basis.*
- *Know the demands and expectations to the design and the documentation for which the employee is responsible, and ensure that he/she has the necessary qualifications and information to carry out the task.*
- *Implement the design-approach within his/hers respective field of expertise and to comply with the company’s demands to the tasks and to the finished product, as well as contribute to the coordination of trade-interfaces.*
- *Know the allotted time-slots for their own work and, in communication with the design management, ensure that the overall time schedule is observed and respected.*
- *Carry out control-tasks of respective work and to otherwise require control of these materials, in collaboration with design management.*
- *Know the company’s (or indeed a client’s/authorities’) demands to the working environment, and actively work to improve this working environment.”*

Both Laseau's, Jones’, Pugh’s and Driscoll's sequence-models deal with ideas, which is rather a hard-to-define concept, delineated in this document not as a belief or an opinion, but as a plan of action, an intention. Thus, an idea in the contractor’s domain of the construction industry can be said to be: *a way to solve a problem associated with a constructability concern, to construct a beneficial and lucrative project.* This arguably goes well beyond purely formal or aesthetic concerns, and also serves to underline the importance of contractor/supply chain involvement, because constructability imparts its influence on *every* aspect of a project, not only the priorities of one stakeholder, such as a client or builder. This leads to assessing the merits of integrated design.

2.1.2 Design approaches that may facilitate Integrated Design

If a company such as a large contracting firm that enters into and manages Design-Build contracts, wants to be able to plan and manage the design of its projects, be able to obtain control of the design processes and to optimize these processes, the primary constituents of the process must be disclosed to the organization. Design needs not be a black box; it can be highly integrative and predictable, but must first be understood. The core processes of project management are planning, execution and control (Koskela & Howell, 2002). Hence, to facilitate administration is to uncover and predict the course of the project, making it manageable.

The following quote (Wiggins, 1989), suggests that analyzing design services, with the objective of being able to plan and manage these activities, is no easy task for the researcher –or the client:

“The act of designing in architecture is a complex process. Many designers, when probed for reasons to explain their actions, are either unable to answer questions, or provide explanations that are not true descriptions of their actions. Frequently the designer will answer that his or her reason for making a particular design decision is based on “feeling” or “intuition”. Under this model the design process assumes a “mystical” aura. Architectural designer can create, yet are unable to say how they do so. Often that which can be explicitly discussed by the designer is the least significant part of his or her design process. It is unlikely that designers are “channeling” information from cosmic sources. Rather, they are working with knowledge that is largely tacit.”

Tacit knowledge refers to knowledge which is practical, but not discursive. Whereas people are able to express and articulate their discursive knowledge, practical knowledge can be drawn on in action, but is not expressed (Mengiste, 2012). This points to a pervasive problem in engineering: namely that of data-loss, which is most commonly connected to the challenges of software interoperability. However, the interoperability view only takes into account the data which has been created and put to use. It does not address the many design alternatives which could have been made, to provide a more iterative and investigative base for verified design solutions through increased quality assurance. Exact, deductive and verifiable argumentation for design choices is a prerequisite for the kind of collaboration that may emerge in integrated practice, for the sake of mutual understanding across disciplines. If the claim that design is principally a social activity (LCI, 2007) is correct, then all trade representatives must be able to convey their specific information needs and how they intend to relevantly satisfy client demands from the perspective of their particular trade. Design methodology is a field which, according to one researcher (Achten, 2007), must adhere to certain standards of credence. Achten states that something may be called a Design Method when it states a clear goal within the process, when it defines steps and the order of steps, when it can be applied to more than one case and when other people can put it to use. Achten also concisely identifies one imperative for rational problem solving in design: as issues occur, the designer should be able to decompose the problem into more approachable sub-problems, integrating partial solutions to whole solutions. However, he states the following: *"For the architectural design managers, it is important to understand a number of widely subscribed key concepts about design. The main one is that design problems are ill-structured at best […]. The implication is that there is no single problem decomposition that will stick from beginning to end; getting to understand the design task is very much related to creating design solutions."*

Designers, in other words, must work exploratively, in direct contact with the problems at hand, for these problems to: 1) be uncovered and 2): be solved, through evaluation and assessment of both problem and method. This continuous evaluation of both method and problem, as well as how these two determinants relate to one another in the process of design is further elucidated by this quote, from an article on "The nature of design thinking" (Dorst, 2010):

"Design projects are hard to plan and control, because they are a mix of a fairly linear problem solving process and an iterative learning process that is driven by the reflection-in-action and reflection-on-action".

This statement points to a need to define activities in the design phases of projects, focusing not only on the deliverables of the process, but for an analysis of processes to be undertaken as well. We can also now point to a "design-mentality" which seems to facilitate the inclusionary nature of integrated design: Decisions are to be made *in planned sequence* to avoid "locking in" inadequate performance by making unalterable, irreversible decisions, because of incoherent/incomplete information, and *at the right time* –early on- to avoid corrections being made downstream (Zimmerman, 2010). This also indicates that BIM/VDC can be used as a "pedagogical" instrument for showing clients or subcontractors a series of design alternatives in a coherent way, providing argument and justification for choices.

2.1.2.1 Delivery processes (Traditional and integrated)

This chart is acquired from a conference paper by two authors, (Ashcraft & Shelden, 2011), one a senior partner at a law firm, Hanson Bridgett, the other a researcher at a software vendor; Gehry Technologies. The phase-sequence is adapted from RIBA, the Royal Institute of British Architects. Both have been adapted to the context of this report prior to its reproduction.

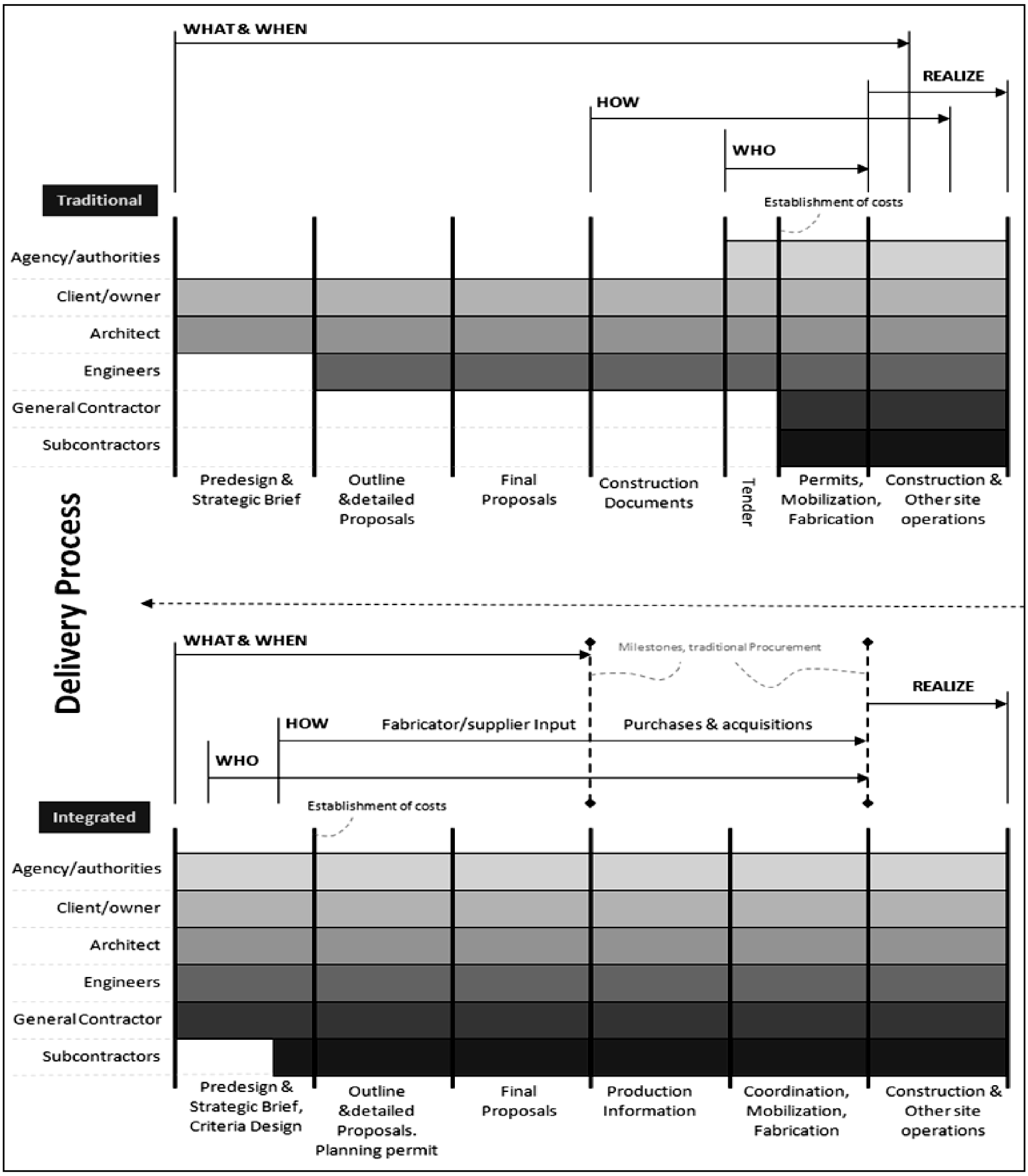


Figure 10, Delivery Processes, by author, adapted from (RIBA, 2012) and (Ashcraft & Shelden, 2011)

2.1.3 Defining an activity in the design process

This diagram, the Activity Definition Model (Ballard, 1999), shows the prerequisites and conditions necessary to perform an activity. The input will be in the form of created content, as outlined in the team-integration diagram and the key information flows table. The criteria are exemplified by the demands to process-planning and specific tasks in correlation with the success measures put forth by the project management/corporate policies, and the resources may also be analyzed by examining the organizational diagram/transaction diagram of the project organization. The breakdown of a specific task can facilitate the planning system greatly.

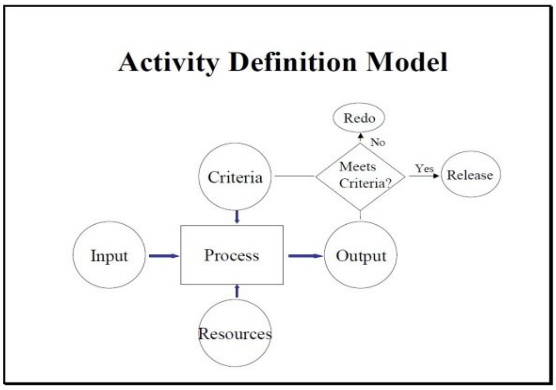


Figure 11, The activity definition model, (Ballard, 2012)

2.1.3.1 Quality attributes requirements

A design solution must meet certain specified criteria, but there is no official limit to how many times a solution may be reiterated. In this document a solution is defined as the process of determining an answer -not as the answer itself. The quality requirements to the specific deliverable and transaction must be specified in the contractual basis of the project, while the process through which a consultant "gets there" does not.

2.1.3.2 Specific tasks of the design phases in BIM-processes

The following list is inspired by COBIM2012, Finland's latest BIM requirements, series 11, "Management of a BIM project", (27/3/2012):

The checklist shows the duties of the coordinator of the design process, not the individual actors:

Needs and objectives assessment:

- Information modeling agreement (contractual basis)
- Assistance in ordering input data model
- Assistance in ordering terrain model
- Arranging for preparation of preliminary requirements model

Conceptual Design:

- Arranging for preparation of requirements model

- Project schedule checking

Design preparation

- Preparation of BIM risk assessment
- Supervision of BIM tasks (on the basis of the contract)
- Reporting on BIM situation
- Arranging for updates to the requirements model
- Further specification of Information modeling agreement
- Organizational planning (team selection)
- Checking designer's selection criteria against requirements model
- Checking design schedule and agreement for complications/omissions

Schematic design, development and detailed design

- Arranging for updates of requirements model
- Updating BIM risk assessments/constructability concerns
- BIM scheduling
- Supervision of tasks and design related quality assurance
- Regular design meetings with reviews and documentation
- Merged models inspection/audit

Construction preparation

- Supervising and gathering documentation and reviews of the design process
- Outlining the contractor's BIM tasks
- Checking of contractor's selection criteria
- Checking of contractor's calls for tenders and checking contractual agreements

In combination, the production philosophy/the company's own guidelines, the success measures and the design process (actors and information flows with milestones) can form the basis of optimization efforts in the design process. Model utilization can serve as the basis of milestone planning and auditing at every "checkpoint" of information transfers, which can provide the contractual and planning templates for negotiation, monitoring and communications. Auditing for quality assurance should be carried out at every transaction of data/information (Laine, 2012).

2.1.3.3 Quality and completion criteria

The following quote, from the journal Construction Innovation vol. 5, (Titus & Bröchner, 2005), quite clearly indicates that what these authors call the "efficiency of a project associate" correlates directly with the sharing of information in a timely, beneficial way as well as knowing and responding to the alternating roles of the actor(s) implied.

"The quality of information received, the timeliness of the manner it is received and the cost-effectiveness in obtaining the information determine the efficiency of a project partner. Another classification [to be] considered is that of the changing roles of the partner with regard to information handling [in the process], i.e., the project partner as a recipient, decision-maker and communicator of information."

The subsequent product description from recent information systems literature (Cadle & Yeates, 2008), provides a comprehensive list for the assessment of outcomes or products that will emerge from a process, rather than specific steps (the process itself) to achieve those outcomes. This is because once a specific outcome has been defined, in the sense that the ends are defined *before* the means, it can clarify the procedure or assign metadata, see chapter 2.2.1.5:

- Purpose
- Composition
- Derivation
- Quality/completion criteria and review methods
- Format
- Related products or contribution

2.1.3.4 The five zeros, a quality assurance system

0 errors in design, leads to 0 errors in quantities, leads to 0 errors in process and logistics, leads to 0 errors in production, leads to 0 errors in handover (Skanska, 2012). This leads to better productivity. It is therefore crucial that not only are data generated but also assured in terms of quality and consistency at every audit. Design planning is intrinsically about risk-analysis and diversion.

2.1.3.5 A suggested framework for quality assurance in Design-build

A relationship between the integrated phase model (Ashcraft & Shelden, 2011), and the design funnel (Pugh, 1990), can be seen. Additionally, a quality assurance agenda (Bogh, 2009), based on By- og Boligministeriet's (now called Ministeriet for By, Bolig og Landdistrikter), *Vejledning om Kvalitetssikring i Byggeri* (2001), can be coupled with the aforementioned models to provide a framework for quality assurance. The LOD concept will be treated later in this report:

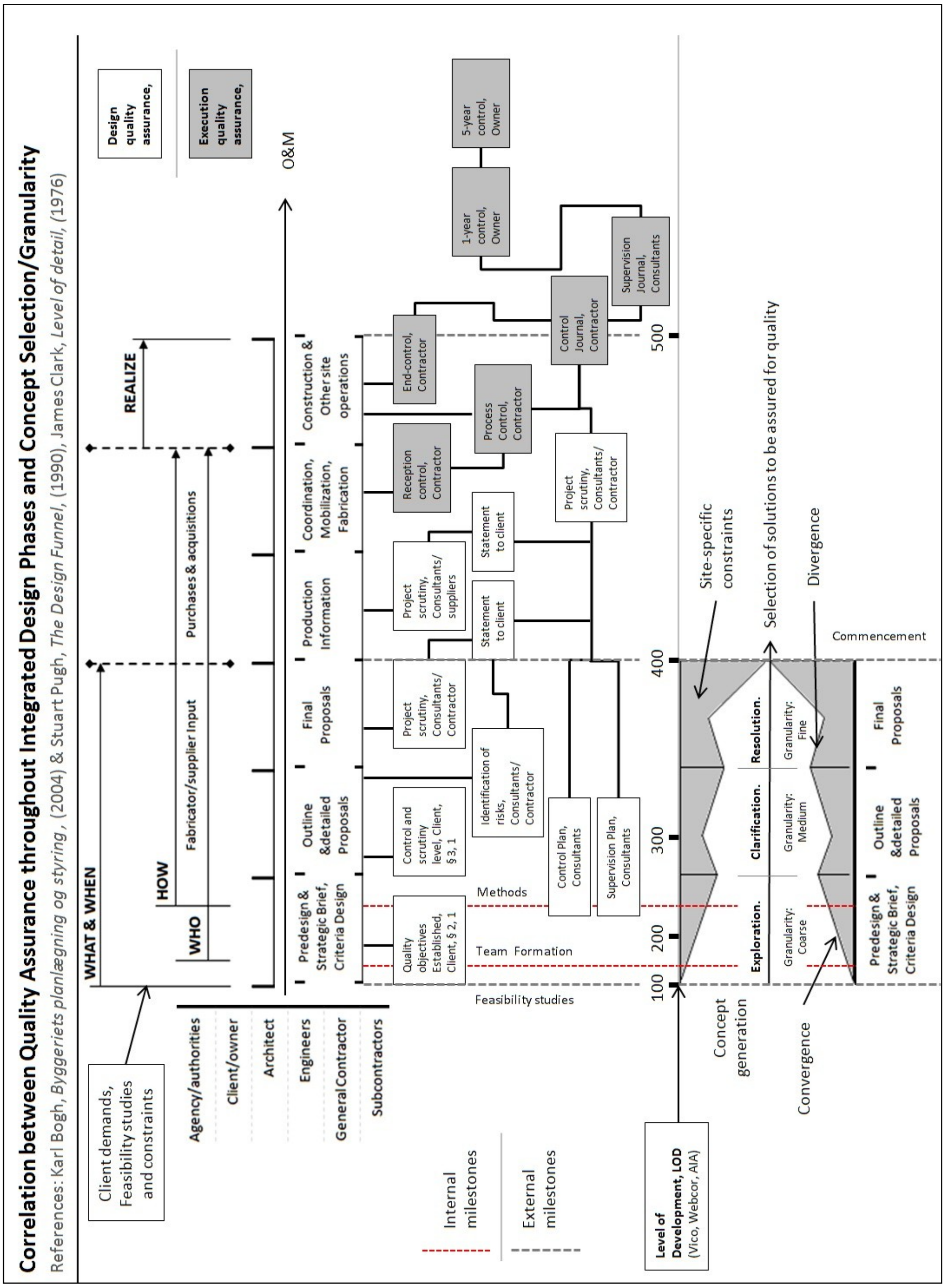


Figure 12, Quality Assurance/Integrted Design phases/Concept selection/LOD, by author

2.1.2 Design Management with Lean

"Design is principally a social activity" - Gregory Howell, LCI

A significant synergy between BIM method(s) and Lean Thinking has been shown to exist (Sacks, Koskela, Dave, & Owen, 2010), in the sense that Building Information Modeling, in an integrated project structure, is an enabler of Lean Construction (Laitinen, 2012). This correlation is assumed as the academic stance from which this chapter commences. The chapter deals with design because, as stated by one Lean implementation-coach, most waste on projects is created at the front end, at product conceptualization, with design driving 75-85% of waste (Huthwaite, 2012).

The basic tenets of Lean Construction are: Customer value, Value stream, Standard Production Systems, Integrated teams, Last planner for production planning and lastly, continuous learning. The following illustration shows the approach (Laitinen, 2012):

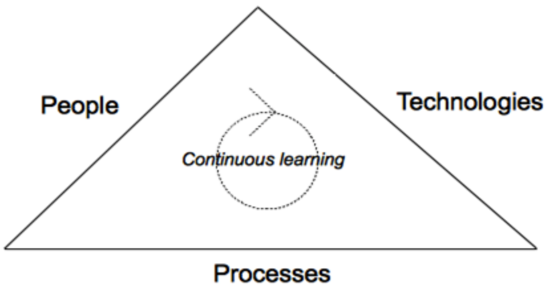


Figure 13, Continuous learning through Lean, by author, adapted from (Laitinen, 2012)

BIM adds value for the customer through the possibility of analyzing proposed solutions and allowing decision making through reliable information. In the realm of Lean thinking, standardization of BIM processes does not necessarily have to do with specific object libraries, or predictable contracts and projects, but could be a standardization of processes, the steering of the project, e.g. through visual and automated checking, or 4D and 5D simulations (Laine, 2012), (Laitinen, 2012). The aggregation of data through effective communication in this simulation and testing environment (VDC/BIM, in other words) is vital for the timely undertaking and conclusion of projects.

Lean Design, as a working principle, elicits a distinction between two different meanings, however (Bertelsen, 2012): one is that the design process leads to a lean, effective construction process, the other; that the design process itself can be considered lean. A so-called "ubiquitous trinity" (Bertelsen, 2012) of factors is said to exist on any project, made up of the *Quality*, the *Price* and the

Time, three factors that will nearly always clash in the trade-offs between one or two or all three, in the efforts to minimize waste of time and resources to the greatest extent possible. One significant point, however, is that “Quality” could also be called “Value”, since quality, as a noun, can also simply mean a distinctive characteristic. To meet or exceed client expectations equals value, whether that may be through iconic forms or predictable outcomes. Value is what the client wants it to be (Cousins, 2011). This relationship between expectations and how they are met can be expressed most simply in mathematical terms:

- Quality = expected quality = 1
- Good quality = expected quality = 1,1 (greater than 1)
- Poor quality = expected quality = 0,9 (less than 1)

Hence, the priority for construction projects can be said to consist of three principles; to keep the work flowing so the involved parties stay productive, to reduce the inventory of materials and tools and to reduce cost (Sowards, 2004). On a Virtual Design and Construction project, the design and specification processes can be likened to a production process (Ballard, 1999). In that sense, a virtual building is indeed a construction site, encompassing every element/activity of a project, represented by way of data creation, although this is still a best-case-scenario.

Bruce Cousins of the American Institute of Architects, AIA, spoke at the conference “TAP (Technologies in Architectural Practice) Faster Forward 2011”, on the implementation of Lean Thinking in Design Management, and how consultants (designers) should adapt to the tendency for contractors to be pushing, and logically so, for more active roles in the design processes of building projects (Cousins, Lean Process Management, 2011). He rhetorically asks the question; *what is not working in the design stage* (?) and replies with the following list:

- Unrealistic production and design schedules,
- Incomplete decisions pushing other decisions downstream,
- Lack of accountability with the team,
- No transparency/Teamwork,
- Frequent reworks

Additionally, "No-one knows as much as everyone" is another relevant point being made to promote what Cousins calls a new operating system of design practice, inherent in the advent of BIM-driven practice.

"Sharing the model, [as well as] the other basic, functionalities of BIM needs a context to work in. Our world is VDC and BIM is the "dashboard for lean processes. Our new OS deals with managing design in a collaborative environment. That is the beginning of our Lean journey". Fundamentally, Lean is *Kaizen,* or continuous improvement, adding value and eliminating waste.

Waste in planning and design, according to this conference-talk, is perpetuated by the following factors:

- Lack of accurate owner program,
- Early starts without complete information,
- Discovery of "unknowns"/lack of sequence,
- Waiting for reviews,
- Predetermined design solutions that require rework to fit project,
- Lack of direct access to the means and methods of the supply chain

In Construction, within the context of this conference-talk but also in general Lean-theory, the main reasons for wasteful practice, or *muda* in Japanese, are:

- Overproduction,
- Waiting,
- Unnecessary transport or conveyance,
- Over-processing or incorrect processing,
- Excess inventory,
- Defects,
- Unused employee resourcefulness

The talk in question, of which this is not a transcript but an interpretation, also covered the speaker's outlook on the current state of Design Management. In Cousin's view, there is a lack of timely client decisions due to the conventional view of design; that it cannot be measured or even explicitly understood. The lack of transparency which seems to be expected in the process is also contrary to the theory of Lean design. The quote below is from David Haynes, also of the AIA, from an article on the website www.aecbytes.com (Haynes, 2012), which serves to emphasize the issue at hand, concerning transparent processes:

"Lean principles of providing value-add to customers, reduction of waste, reduction of complexity, and increased speed are all improved through the transparent information that BIM can provide"

The concept of transparency is tied to collaboration. It is in the multi-disciplinary, trans-disciplinary or inter-disciplinary teamwork that the transparent, integrated process can come to fruition. Collaboration, however, is more about benefit than motivation (Deutsch, 2011). Therefore, one entity (project stakeholder) must be as proficient in the use of the technologies that allow for collaboration as the rest of the team, since a shared risk and reward contract will only be as secure as the work of the least proficient member of the team. Also, in Cousin's view, rework is inevitable; the direct participation of/in the supply chain is done at a time much too late for it to generate revenue, making the design management undisciplined and causing virtual building models to be used primarily for presentations.

According to the conference-talk in question, this current state and its inherent issues needing resolution, is brought about by the notion that design projects are all unique and therefore cannot be planned or managed fully. Cousins argues that design is, in fact, understandable and measurable and consequently *can* be planned and managed. How do we, in a Danish context, go about this planning and management?

2.1.2.1 Working with the correlation between BIM and Lean

Lean is recognized as a planning method which is highly applicable in repetitive production environments, which produce in varying or persistent quantities.

One example of a method from the lean approach is Last Planner (Howell, 2000). "The last planner" is the person or team that sets forth assignments to be resolved. The following diagram (KarlsruheInstituteofTechnology, 2010) shows the basic system:

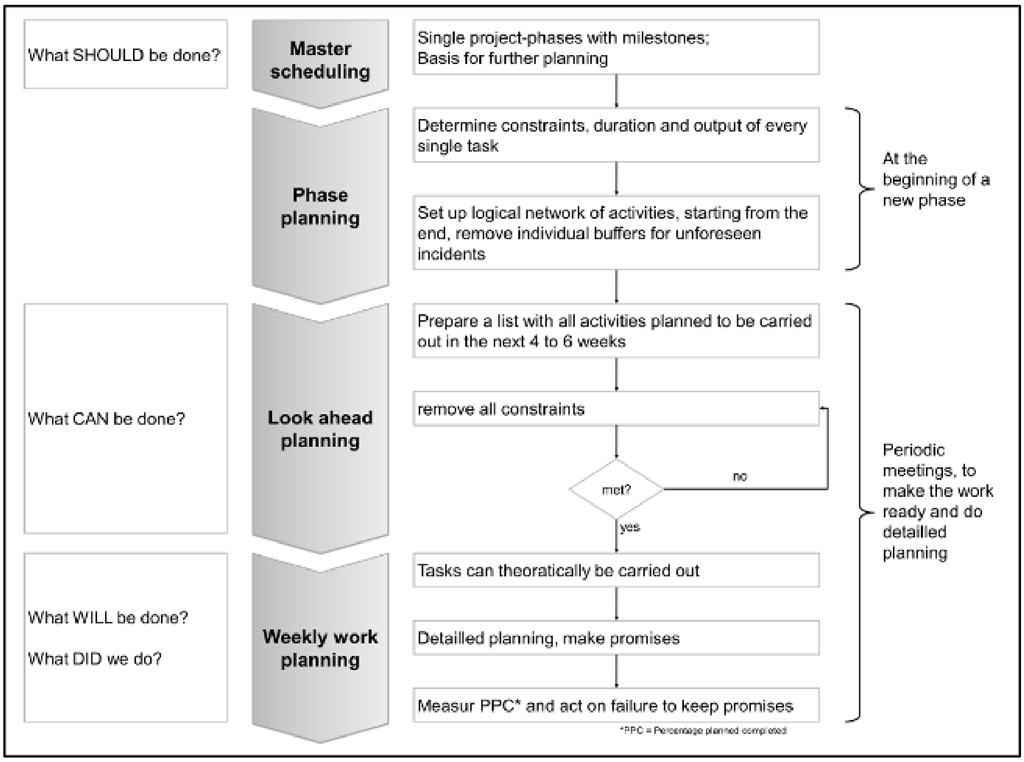


Figure 14, Last Planner System, (Howell, 2000), (KarlsruheInstituteofTechnology, 2010)

The diagram indicates the stringency with which plans can be made, cf. the COBIM list of activities requirements, series 11, “Management of a BIM project”, (27/3/2012).

The more severe a planning effort is, however, the higher the risk of failing to meet the deadlines will be.

2.1.2.2 Design management in the context of digital collaboration

As we have seen, the primary tasks of management of the design and specification phases of a project encompass (Olsen, 2011): quality assurance (in relation to client demands and company policies), economic planning, time planning, selection of methods, selection of technologies, economic planning, regulations-compliance, ensuring a proper working environment and risk management.

Managing tasks and resources (which coalesce into activities) over time is highly significant, because for the work to be finished on time, different trades/disciplines are to be coordinated, important decisions must be facilitated and made on time, the necessary resources must be present, approvals must be present and all stakeholders must be involved at the right times for their respective contributions.

The following known cost-carrying circumstances (Olsen, Anlægsteknik kursus, 2011) for construction projects can be alleviated in the building process through standardized methodologies and production-support; by way of BIM and Design-Build arrangements:

- Unique/singular production bases, engineered-to-order designs
- Many different stakeholders on the project
- Interim/site specific production methods

Structuring project information can be done on the basis of different approaches to the work:

- Product functions (e.g. specific service/utility)
- Geography (e.g. location based planning)
- Responsibilities and contractual arrangements (e.g.
- Phases of the project

What the design and specification department on a Design-Build project chooses to use as a means to arrive at the desired overview of the processes, may depend on the specific project team and the use of supplementary abstraction mechanisms. Classification/composition systems, the configuration of software-specific modeling tools (file-based, central database, etc) or any other such defining apparatus, will be part of the structured work flow.

2.1.3 Time planning of design services

Time planning can be done on several levels of abstraction. The typical levels on which time planning schedules are represented are as follows: the master plan level, the process plan level, the period plan (5-8 weeks, for example) and the week plan (1 to 2 weeks, typically). Of special importance to the Design-Build process, however, in the integrated work being carried out, are milestones, the points at which information transfers and deliveries take place. A milestone is not necessarily an interface between two phases or stages of a project, but rather a prognosticated point on a timeline, recognized when successfully reached. Milestones are the constituents of a time plan and often create forward momentum to propel the project along to completion (Edwards & McDonough, 2011). Also, milestones can be utilized as primary checkpoints to assess how a given project is doing and whether or not the project is on schedule and on budget.

2.1.3.1 Different types of milestones

The following types of milestones are not ordered by scale or level of detail, but rather by type. Another way to categorize these types could be by order of the stakeholders implied, all capable of appointing these milestones to the schedule, through their inputs:

- Start time(s)
- End time(s)
- Coordination points
- Decision points
- Approval points

2.1.3.2 Guidelines for Setting Milestones

The person responsible for selecting the specific types of milestones should be conscious of these five parameters (Edwards & McDonough, 2011):

- **Frequency** – A project manager may be tempted to overuse milestones as a stimulus tool to keep a design team moving to reach a desired outcome, but shouldn't trust the temptation to label every task completion as a milestone. In turn ignoring or not recognizing significant and relevant events as milestones particularly at junctions of the critical path is another extreme. The approach is to consistently designate important deliverables as milestones.
- **Timing** –Milestones with intervals that are too far apart will not have the benefit of the drive generated by a motivated team in recognizing major achievements, as well as minor goals met. In principle, the spacing of milestones at intervals no longer than every two weeks for projects of several months in duration can be considered appropriate.
- **Visibility –** The need of milestones to be placed notably in the project's schedule and tracked periodically provides significant value to a milestone.
- **Accountability** – Milestones, as commitments, must be met on time. If a milestone is missed, it should be checked thoroughly and immediately, the resources reexamined, to determine if these are properly matched to the objectives intended.

- **Fallibility –** The project manager should decide on demanding milestones that carry a degree of risk for failure, counterintuitive as that may sound. Milestones are also learning experiences and can be seen as opportunities to make adjustments early in the project's execution, and optimize the scheduling.

By keeping these guidelines in mind when planning milestones, the project manager will able to achieve an appropriate balance between the easy and the challenging milestones, that can motivate team members to stay energetic and feel a greater sense of accomplishment, when these milestones are met.

2.1.4. Project-Optimization as approach to quality management

A recent guideline (09/2012) on project-optimization of design and construction projects was published by "Værdiskabende Byggeproces"/"VærdiByg", which translates directly to "Value Creating Construction Process" in English. VærdiByg, a conglomerate of industry practitioners and organizations, has circulated this guideline on their website. The following quote, taken from the website, outlines a common mission statement:

"The purpose of this co-operation is to find and develop best practices for creating and maintaining value in the construction process across the different agents in the construction sector and through-out the entire construction process." (www.vaerdibyg.dk).

The particular guideline in question (VærdiskabendeByggeproces, 2012), addresses project-optimization as a collaborative effort in the form of workshops or interdisciplinary exchanges between stakeholders. It is a method which should be implemented immediately after the contract has been negotiated and stipulated. The purpose of this is to obtain the most favorable solutions, optimal constructability and agreements on the design and construction processes which follow. The main reason for this is to ensure that the optimization efforts do not change the project material considerably as compared to the tender and procurement documentation.

VærdiByg most adamantly emphasizes that it is the client who must make the relevant demands to the project team to carry out the interdisciplinary workshop(s) at appropriate times. On the whole, the constructability aspect of the guideline's instructions is catalyzed by the early involvement of suppliers and contractors, which in itself is not a novel idea, but there is more to its principal approach than scrutiny/consistency control; namely the client's own qualitative assessment of the solutions proposed and that making the process dependent on that authorization should be a contractual prerequisite for entering the case. Naturally, these assessments have to be worked into the project, and so it is also a prerequisite that any changes to the material be delegated to one of the contributing parties, as in either the consultants or the contractor. Integrating the contractors' specialist knowledge also implies that the project material will inevitably face rework. The responsibility for this is also to be specified at the signing of the contract, because the rework may create one more information transfer, which is not necessarily advisable, since information may be lost at every transfer. However, the chance for the contractor to challenge the project at certain stages of its development, in collaboration with the client and the consultants can ensure, or at least facilitate, constructability on site. Hence, the aim is to achieve an execution process as robust, yet as responsive to alterations, as can feasibly be done. Conversely, whoever assumes this "challenging role" on the project, be it a representative of the client or the contractor, should be a person with no direct management responsibilities in the actual project, since that may lead to bias.

Practically, on a building case, stakeholders prepare optimization proposals before the workshops and whereas consultants may focus on potential quality or behavioral enhancement, the contractor and suppliers may focus on time- and financial aspects of the proposed changes. One aspect should not be disproportionately favored or focused on, since any unilateral focus could lead to a downgrading of other aspects.

VærdiByg has set up the following four points of emphasis:

- Products and Solutions
  The contractors or other stakeholders may want to suggest specific solutions or products, even before the purchasing department gets to work.
- Constructability and Working Environment
  This entails project (models/drawings/documents) scrutiny and the contractor's assessments of potential bottlenecks.
- Construction Process Optimization

Different working sequences on-site than those specified in the project material may alleviate foreseen problems.

- Economy

  Any change should be tracked in accordance with the total economy of the build.

All in all, the claim is that a flexible, responsive process can lead to optimizations on site, provided that the process is simultaneously structured to validate the inputs of every stakeholder.

When the potential pitfalls have been identified and remedied to the best of the project team's abilities, it also implies that these tasks can have been delegated through a Last Planner/best person practice approach. When the critical tasks have been identified and delegated, the time plan can be made considerably more precise, e.g. since a specific subcontractor will have had a chance to convey to the design management what these critical tasks include, and by which measures they should be handled. This will also be able to support health and safety planning because of the regular commentary from subcontractors and moreover, as certain critical activities will inevitably be more high-risk than others, the more rigorous quality assessment efforts on-site can be determined and coordinated with the ongoing execution works.

2.2 The integrated Practice as collaboration principle

This chapter is about collaborative work in architecture, engineering and construction projects and processes, with the design stages as the primary focal point.

2.2.1 Implications of sharing knowledge in a design process

Examining the outcome of a design method, i.e. the building as an entity, can be done just like one would look at a car or an airplane. In other words; it may be viewed as a delimitated system. The socio-technical and interdisciplinary process of design itself may be more ambiguous, however. Despite the fact that design activity does in fact lead to an outcome in the form of specifications, documents or simulations, it, unlike the built facility, is a dynamic information carrier, one that may yet be reiterated or contested through the interdependent, coherent tasks carried out by design professionals and their instruments. As banal as this observation may seem, it should be underlined that the continuity of information sharing stagnates somewhat with a “fixed” and hand-off ready solution, which may not warrant change or improvement (Partridge, 2008). Examples of such solutions could be drawings or descriptions of activities, artifacts lending themselves to planning and prognoses because they will be perceived as products which should not be altered or modified after a certain phase and consequently information exchanges may be forecast and contracts signed, conveying the delegated tasks to be worked into budgets and schedules.

The integrated design process, with its simultaneous parallel feedback, as made possible by information modeling, assists an adaptive and respondent process. In settings where decision making is being facilitated and interdisciplinary activities take place, e.g. checking for consistency in synchronized, trade-specific models in a virtual BIM environment, integration is a necessity. One procurement method becoming, if not increasingly widespread, extensively discussed in professional circles (one search engine query showed 14 million results), is Integrated Project Delivery, or IPD. It is highly dependent on the contractual / social factors of collaboration.

“Respondents suggest trust, respect, and good working relationships are the key to successful IPD projects. Many believe IPD cannot work without these relational factors and indicate monetary incentives are not the most effective at fostering collaboration.” (Kent & Becerik-Gerber, 2010)

Teams are groups of people with complementary skills who are committed to a common purpose and hold themselves mutually accountable for its achievement (Katzenbach & Smith, 2003). The gains attainable from integration of team members on projects include, among other things (Denton, 1997):

- A better range of ideas than individuals working in isolation
- More effective responses to change
- Better understanding of the needs of other disciplines and the place of one's own contribution
- Better decisions and more refined solutions
- More efficient use of resources, especially time.

A planning system is, in principle, straightforward; the planner analyzes the various deliverables, the information parcels, in relation to each other and considers how one is transformed into the next. These deliverables flow between not only different formats, but different stakeholders, different infrastructures and different organizational cultures altogether. However, the level of detail required in the planning system will depend on the type of alteration being considered. We can break down identified activities until we arrive at tasks that are "fairly atomic", that is do not readily subdivide further, becoming small enough in scope to estimate with reasonable accuracy (Cadle & Yeates, 2008).

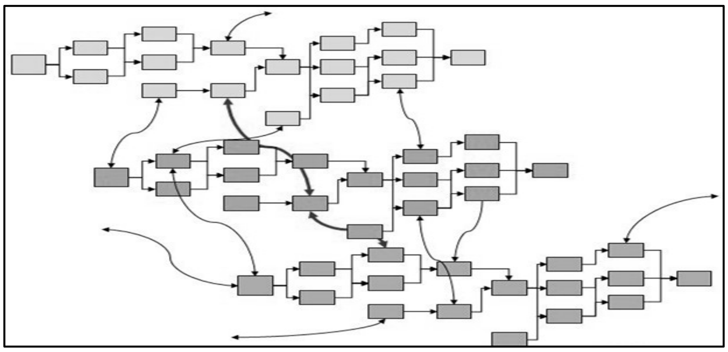


Figure 15, A graphical representation of a value-network in a construction context (Wandahl, 2011)

An information parcel is essentially a product that is delivered from one agent to another in a more or less predictable value-network. This deliverable, which is brought about by imports, content creation, modification, exports and transfers, as well as coordination efforts and integration across the professional interfaces, is either an end-product, or a transitional product created on the way to the final product (e.g. a design of a structural element), but cannot be considered a deliverable in its own right.

The continuous alterations and development (iteration) of information is fundamental to the design process in Design-Build projects. The rationale for this statement is that, provided that the Design-Build arrangement does indeed call for integration of stakeholders at every evolutionary stage or milestone of the design (whatever terminology determines our rhetoric); the Design-Build process will be made up of non-linear, dynamic interactions. An example could be various actors, all subjects to contracts on many different projects in a portfolio. In this case, portfolio management quite simply limits the actor's ability to work on the project at hand, when he or she is away, doing other projects. This infers that every decision affected by the actor's presence, or absence, will have not only consequences for that one project, but for the portfolios of every other actor as well as parallel projects of their own. From this perspective, the move from micro-economy to macro-economy is not a huge leap. The same type of complexity can be observed in the individual projects of an organization; multiple tasks for each actor may lead to a dispersion of efforts (resources and activities) on the project as a whole.

The apparent complexity brought about by the unpredictability of such a process suggests that it might not be possible to establish an exhaustive approach-model for all design processes, but rather a generic approximation. The approximation still needs to be as rigidly defined as possible, while allowing for the complexity of the interdependent design activities to arise. This is what makes the integration of various disciplines an important precursor to practice re-design, or refinement of an existing business process, in relation to managing Design-Build processes.

A complex system (Lucas, 2006), is defined as a functional whole consisting of interdependent and variable parts, in which the parts need not have fixed relationships, fixed behaviors or fixed quantities. *"Digital interaction of any sort is […] a graphic model of the complex process of communication."* (Cham & Johnson, 2007).

These inherent complexities lead to an analysis of why informative transactions are necessary in a Design-Build process.

2.2.1.1 The significance of informative transactions

Regarding the coordination of stored in data/information for the virtual building and its progressive level of detail, as the project evolves. What is needed to define interactions and tasks is a model-driven process, a representation of when information exchange occurs. (We may call that the scheduled release of datasets). In other words, it is a method to survey and record the information needs on a project.

At this hypothetical point, a clear imperative to assign information levels or levels of detail to the demanded /needed information in the representation becomes apparent. To accommodate to this, either the information levels 0-6 from DetDigitaleByggeri, an industry organization in Denmark (DetDigitaleByggeri, 2011) can be used. Alternatively, a Model Progression Specification, MPS (Bedrick, 2008) (Vico, 2012), may be applied to this process. Both provide a consolidation of the phases in planning and construction, but with the potential for breaking into many more sub-phases/stages. It may contain many different levels of detail, one for each deliverable in the stage and can contain many different tasks, assigned to various people in different trades and stages. At the core of architectural design is the process of moving from approximations to progressively more precise information. It thus becomes a framework for a written checklist of evolving elements, with regards to parameters, from schematic to as built (i.e. geometry and other data).

The Level of Development hierarchy looks as follows (Vico, 2012), with the “equivalent” Danish information levels added for comparison:

- 100. Conceptual level = BIPS/cuneco 1
- 200. Criteria design/early estimation = BIPS/cuneco 2
- 300. Detailed design, exact geometry etc. = BIPS/cuneco 3
- 400. Fabrication level/production level = BIPS/cuneco 4/5
- 500. As built. = BIPS/cuneco 6

An example of progressing levels of detail, with geometry as only parameter as arranged by “visual impact comparison” (number of vertices), see figure 16:

Figure 16, Progressing levels of development, (Source unknown)

This principle can be directly applied to building models with data on every aspect of the conception, programming, design and construction processes. In practice, at any given stage or object-specific delimitation within the project, the LOD signifies the overall stage, the classification and the level of detailing, cf. figure 13. One obvious shortcoming of the illustrated example, however, is that the level of detail in the various phases in the schedule, listed as *conceptualization, criteria design* and *Detailed design,* follow these phases very strictly and nowhere do we see any deviations*:*

Element (ASTM Uniformat II Classification)				Level of Detail (LOD) and Model Component Author (MCA)					
				Conceptual-ization		Criteria Design		Detailed Design	
				LOD	MCA	LOD	MCA	LOD	MCA
A10	Foundations	A1010	Standard Foundations	100	PD	200	DC	300	TC
		A1020	Special Foundations	100	PD	100	DC	300	TC
		A1030	Slab on Grade	100	PD	200	DC	300	TC
A20	Basement Construction	A2010	Basement Excavation	100	PD	200	DC	300	TC
		A2020	Basement Walls	100	PD	200	DC	300	TC
B10	Superstructure	B1010	Floor Construction	100	PD	200	PD	300	PD
		B1020	Roof Construction	100	PD	200	PD	300	PD
B20	Exterior Enclosure	B2010	Exterior Walls	100	PD	200	PD	300	TC
		B2020	Exterior Windows	100	PD	200	PD	300	TC
		B2030	Exterior Doors	100	PD	200	PD	300	TC
B30	Roofing	B3010	Roof Coverings	100	PD	200	PD	300	TC
		B3020	Roof Openings	100	PD	200	PD	300	TC
C10	Interior Construction	C1010	Partitions	100	PD	200	PD	300	PD

Figure 17, Level of Development, (Vico, 2012)

In the example in figure 14, however, the bolted flange connections have reached a considerably higher LOD than the connected beams & columns. The connections might be level 500, whereas the beams and columns might presumably be at level 200. This could well show the difference in detailing

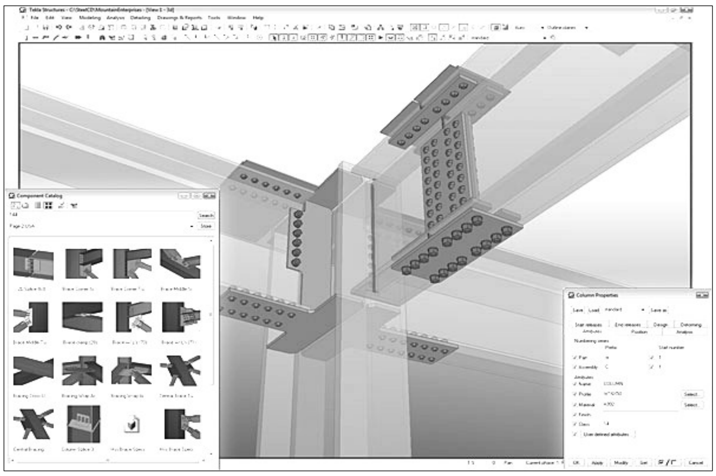


Figure 18, Example of a model of structural steel with deviations in detailing, (Source unknown)

between that which is delivered by the architect or designer, shown by the beams and columns in the visualization and that which the fabricator of the specific element type, shown by the connection details, will deliver -at the level on which they themselves operate. This is a realistic scenario, since the various trades will operate in different levels of abstraction on a project, because they traditionally belong to different phases of procurement. It would seem that this is an absolute indication that a project as a whole is not lifted as one entity, in one increment. Virtual buildings, in the form of information models, *can* evolve in cumulative advances in several "places" at once. From this, we can rationally deduce that the Design-Build arrangement must inherently be a farewell to the phase-model of linear construction practice.

2.2.1.2 Key Information Flows

Flow Title	**Flow content**
Structural architecture	The architectural information required by the structural engineer
Structural services (MEP)	The architectural information required by the services (MEP) engineer
Architectural structure	The structural information required by the architect
Architectural services (MEP)	The services (MEP) information required by the architect
Analysis model	The architectural information required by the performance analysts
Results	The results of analyses required to perform design
Construction scope	Information required to specify the contractor's scope of work
Status/RFI's	Status reports and requests for information, from fabricators upwards
Structural scope	Information required to specify contractor's scope of structural work
Services scope	Information required to specify contractor's scope of services work
Fabrication details	Information generated by fabricator that impacts architectural design
Directives	Information required to govern on-site execution
Purchase scope	Information required to specify scope of bought/planned items

Table 1, Key Information Flows (Crotty, 2011)

The table above, (Crotty, 2011)**,** shows key information flows between stakeholders, which can be used in combination with an organizational diagram to identify relationships and contracts.

2.2.1.3 Team integration through information flows

A prerequisite of the decision-intensive early design process in BIM is an integrated team working on the project as a whole (Deutsch, 2011). One way to visualize the project stakeholders, combined with the information flows, is by way of an organizational diagram showing transactions:

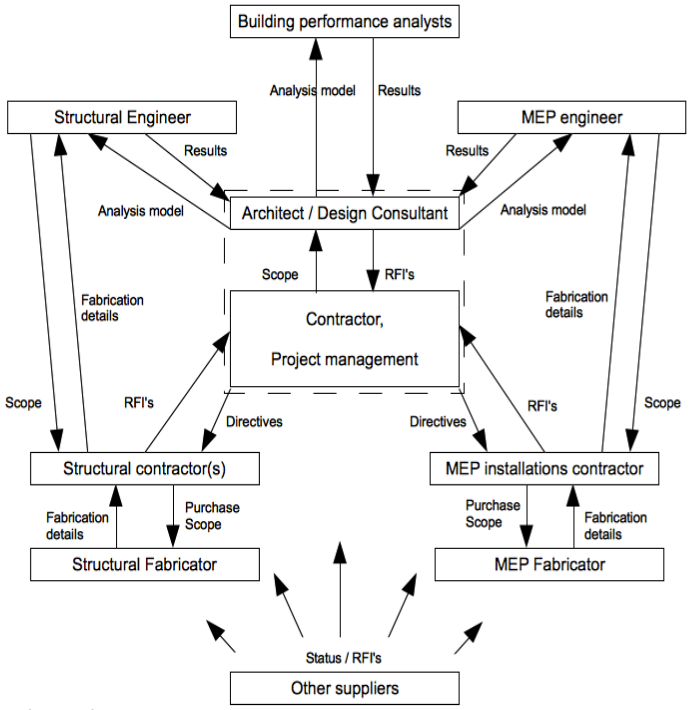


Figure 19, Transaction diagram, by author

2.2.1.3 Organizing team composition

(From the intranet of the collaborating company, anonymity preserved): After the reassignment of the case to the design team, a group of individuals is composed to solve the design tasks, depending on the relative size and complexity of the project. A design and specification team consisting of internal and external consultants, as well as the necessary consultants (acoustics, geo-technics, etc.) is set up. On large and complex projects, numerous autonomous teams may be formed. The criteria for selection and composition of the organization are:

- Professional competencies
- Motivation
- Ability to cooperate
- Capacity
- Experience

- Professional competencies implies that the task must be able to be solved in a technically sound and professional manner within the given prerequisites, and reference material from similar assignments must be available or be found.

This evaluation happens on a company level, but demands to individuals will be set, with regards to complex assignments. In the event of lacking knowledge of an employee’s competencies, a résumé should be demanded to document the skills needed to perform the task.

- Motivation: This implies an intense focus on the task at hand. On a personal level (the interesting assignment), as well as the company level, it must be ensured that the specific assignment is given enough attention, and will not become insignificant in the context of a large organization. This is imperative for success.
- Ability to cooperate: oftentimes a failure in the design process infers that different stakeholders have not communicated, as in, closed the professional gap. Or, that information regarding changes is not conveyed quickly enough, if at all. This is a waste of time and money, and the organization at large feels the impact.

In the formation of teams and selection of cooperative partners, knowing the individuals beforehand presents considerable value for the project. Oftentimes choosing participants on the basis of good cooperation and communication skills can be more favorable than choosing on the basis of a price.

- Capacity: The crux of the issue is being able to solve an assignment in the given time slot. Enough people must be assigned to the task - especially from the beginning, when it is crucial to start off quickly. If this effort succeeds, the motivation will be in place; relevant systems are secured and put to use early on and can be instrumental in saving time and efforts later on in the process.

The opposite of the desired condition, the under assigned organization, in which the few people present constantly have to address delays, will lose the holistic view. This costs time and money.

Many reasons why adding more personnel to a task in the process may emerge. This must be attainable without going through organizational crises. At the time of signing the contract, it should be ensured that the relevant partners have the necessary reserve capacity to add resources if the project requires such measures.

- Experience: The team on a given assignment should be is selected in a way which ensures that the team holds the necessary experience, as well as people who can talk to both subcontractors and the general management.

2.2.1.4 Potential impacts of process-mapping on contracts

Value Stream analyses and process mapping as prognoses for inbound and outbound information logistics can serve as the basis for contractual relationships in accordance with a selected collaboration principle, through sustainable processes (less waste through optimization of the plan).

- The protocol based on the mapping of parcel transactions within the technological infrastructure, to formulate a generic approach to designing projects, can serve as the guideline for the collaboration principles applied, such as the IPD approach.
- This suggests that arbitration of disputes can be referred directly to the dynamic (continuously updated) mapping of services in the work flow.

Figure 20, Collaborative design-build roles and work flow, by author

The diagram above (by the author) was made to convey how mapping can include roles, responsibilities, dispatch and recipient control of project material, basis for contractual obligations and the phase model of a project. (Please see diagram in detail in the annex of this report).

2.2.1.5 Interoperability as prerequisite for Design-Build

This chapter assumes its point of departure with the following approach, put forth by Randy Deutsch (Deutsch, 2011): To put a building model to the full potential of its utility, obstacles to successful collaboration must be alleviated or removed. When addressing collaboration and integration in Design-Build projects, the interoperability of tools (software-tools, in this case) and thereby work flows, firm culture, communication and responsibilities, is a most significant factor. The large software vendors, as makers of tools that have considerable ascendancy on the aforementioned factors, exert intense influences on the work flows of the various trades that contribute to the planning and management of architecture, engineering and construction projects.

One ample representative of the software vendor and distributor field is Bentley Systems Inc. As a company, they voice their willingness to embrace the opportunities that collaborative practice promises, through interoperability (Thein, 2011):

"Greater interoperability is a prerequisite to significantly improve building processes […] Bentley recognizes that the ability to open files in other user formats is crucial to the successful, cost-effective design, delivery, and operation of […] assets."

Another representative of Bentley Systems Inc, Volker Mueller, delivered a talk at the conference "Build Boston 2011", on "Developing Open Systems and Methods for Collaborative Modeling". The conference talk, of which this is not a complete transcript but rather an interpretation, was begun with the following list on the subject of "The reality of AEC/O processes". In the opinion of the speaker in question, the reality is that the processes are generally:

- Collaborative,
- Dynamic,
- Asynchronous,
- Content-rich,
- Non-linear,
- Multi disciplinary,
- Trans-disciplinary

Having recited the list, the talk continues: *“various parties work with varying intensity, in a multitude of document formats, using a variety of tools. In one word: Messy. This contrasts with the desire to design intelligently. Teams want performance feedback during design and later, constructability feedback […] They may desire any other parameter tracked, analyzed or simulated and feedback about how it behaves, as the design evolves. This requires freedom and flexibility in deciding which data are required [and] which design tools are used. Selection of analysis tools must remain unconstrained by design–tool usage, in order to provide continuous feedback.”*

Mueller states in his talk that these goals can be summed up in four words: *Open Systems and Methods*. “Systems” implies an extension beyond data, to the entire infrastructure of AEC projects, and “methods” emphasizes flexibility in how project teams work. Additionally, four learning goals for software vendors and practitioners alike were presented by Mueller, as areas where the industry can improve its methods. The terms were stated in the following sequence:

1. Quality of design
2. Quality of processes
3. Analyzing data exchange needs
4. How to map data

In Mueller’s own words (Mueller, 2011); “quality of design” is based on frictionless integration of relevant design-team contributions, in the scrutiny of as many performance indicators as the design team wishes to impose on itself, whereas “quality of process” [is to] eliminate information loss and instead enhance growth and enrichment of information, […] increasing the quality of operations. “Data exchange needs” can, in Mueller’s opinion, only be decided by the cooperating stakeholders. From the talk (Mueller, 2011): *“The participating disciplines determine which data are needed. […] Specific project conditions also include the intended methods. These determine which tools will be used by the team, which in turn affects the data collection and the exchanges that need to be supported”.*

These three aforementioned goals were all covered in the talk, areas which the collaborating company are also currently working on; cf. the PhD-projects the company is currently funding, among other efforts. However the fourth goal; *how to map data between storage formats, design* *tools and analysis tools in all phases of the facility life cycle*, was not. That led this project to pursue answers from the researcher/practitioner in question: Mr. Volker Mueller of Bentley Systems Inc. The following correspondence ensued, published with permission:

Tuesday, October 16, 2012 3:07 PM

Dear Sir,

I have watched your presentation at the Build Boston 2011 conference online (youtube.com), with profound interest. Your e-mail address was given at the very end of that. I am currently in the process of writing my master's thesis from the University of Aalborg in Denmark. I am enrolled at the School of Engineering and Science, Dept. of Building and Construction.

My civil engineering specialization is in Building Informatics, a field with a distinct emphasis on digital methodologies in communications, technology and processes, in the entirety of a building's life cycle. I am writing this letter to respectfully address you as a dynamic, forward-thinking researcher to shed some light on the issues you brought up at the specific talk, namely learning goal number 4:

How to map data?

I have requested to join the LinkedIn group, but wanted to address you directly to hear if your group has covered much ground on this specific subject since then and, if so, there are papers or articles that I may give a read?

Thank You in advance, Sincerely

Joakim Lockert

Aalborg University, School of Engineering and Science, Institute of Building & Construction, Building Informatics CST

Tuesday, October 16, 2012 6:37 PM

Dear Joakim Lockert,

Thank you for contacting me. First, I had to watch my own presentation again to establish a shared frame of reference. As you may have realized, the learning goal “How to map data?” was not covered in my AIA-TAP presentation at Build Boston 2011, with the reasonable excuse that there just was not sufficient time allotted for the presentation to cover this question. As you may have sensed, this was a tactical maneuver.

In the Open Systems and Methods for Building Environment Modeling (BEM) group currently the predominant belief is that this data mapping may be implemented successfully by using many purpose-built one-to-one mappings between any two applications in the system, and that the system grows by voluntary contribution (or commercial offerings).

While I agree with the main goal of the Open Systems and Methods for BEM group, I do not believe that the currently favored approach of using many one-to-one data mappings will lead to a sustained success, because that is where efforts started in the past decades. After all this time those efforts have not succeeded –**or have actually failed**. Based on these chains of one-to-one mappings and the ensuing dependencies, workflow or dataflow design and implementation for practical purposes will become tedious, error-prone, and subject to break down due to version incompatibilities or missing links. In my opinion one could characterize this as an approach that lacks the robustness that is required in a professional environment that needs to be able to rely on predictable performance not only of its products but also of the data it uses to create those products, and, of course, of the corresponding software tools' reliable access to these data in terms of creation, representation, manipulation, interpretation, maintenance, etc. over the project design and construction cycle, which even for moderately sized projects may stretch across a few years, and for complex projects may even exceed a decade. The obvious alternative is to find shared ground, a common language, to which applications map one-to-one; however, because all applications map to this shared data format, no application has to do more than this single one-to-one mapping in order to communicate, i.e. exchange data, with any other participating application. This is certainly the scheme pursued by many shared data formats, which again indicates a major challenge, which is the challenge of **standardization** as reactive process. IFCs are an example of that approach. However, there is a general development of using systems that are more openly accessible –like XML formatted data representations rather than binary formats– and in my opinion upon time these open formats will be automatically analyzed and semantically mapped from one to another. This means that the shared schema could be automatically constructed and extended, rather than being created by human-driven dogged-down consensus processes which tend to be very complex and will progress very slowly, preventing them from catching up and keeping up with the pace of innovation in design and construction processes, as well as technologies, and the software applications that support these processes.

The company for which I work, Bentley Systems, is interested in accessing more data than our own tools can create. Therefore, we have been working on our own data schema that fulfills some of the more complex requirements not yet met by IFCs. It allows us to proceed with one-to-one mappings from all our applications to a **single data spine** rather than having to deal with many-to-many mappings between all our applications. This is especially important because this approach provides our customers with the liberty to mix authoring and analysis tools to suit their needs rather than **being stuck** with what is defined by some limited implementation of data pathways which then proscribe which tools may be used. Note, that the data spine is virtual and may consist of many data entities stored in various locations in some type of federated scheme. Of course, this is work in progress. Some of Bentley's applications have already implemented that way of representing their data. In a way any consuming application would find the data it needs and not bother with data that are irrelevant to it; however, in general all applications participating in this scheme have access to all business data stored in it, e.g. any entity's properties stored in this scheme can be read by any application that knows how this works, i.e. read the data tags and the contents and represent them to the software's user. The software itself does not need to understand what the tags mean in order to show their contents to the user. The user nevertheless will benefit from being able to access that information, if applicable.

As of yet, these developments have not been published; therefore, I cannot point you to any specific papers that would illuminate better what we are doing than my verbal sketch of the system provided above. However, the effects of these developments are visible in an increasing number of Bentley's software applications. There are white papers available at bentley.com which are indicative of Bentley's support of open data formats.

Regards,

Volker Mueller, LEED AP

Research Director for Computational Design, Corporate_Headquarters:
Bentley Systems, Incorporated, 685 Stockton Dr, Exton, PA. 19341 - USA

On the basis of the exchange with Mr. Mueller of Bentley Systems Inc, it is evident that one-to-one data mapping does not serve its intended purpose, namely that of providing a platform for collaboration. In fact, Mueller's work suggests that a one-to-one mapping approach seems to directly counteract the need to handle large volumes of data efficiently, integrated from many sources.

The prevalence of these many sources on any modern-day building project emphasizes the need to be able to manage provenance (origin), quality, even proper attribution and citation (for example by logging contributions). With all these data, shared or disbursed to many contexts, it does indeed seem like some of the key stakeholders in the vendor-circuit attempt to protect market shares by not straightforwardly supporting open systems, e.g. through using proprietary formats.

The standardization efforts brought up in the reply also suggest that the vendors play a major role in collaboration, because the tools that people work with can, to some extent, dictate the kinds of collaborations that people can be subject to. This will have an effect on the long term, in the kinds of contracts that designers/consultants are willing to abide by, since zero interoperability potentially means zero collaboration. Formatting is highly relevant to integrative work flow, because first off, the data formatting principle is something not at all exclusive to the construction industry. All computer data is formatted in one way or another, and relevant data to designers do not necessarily come from other stakeholders in construction. Examples could be meteorological or geographical data to be attributed to a building model/object. One researcher with an ostensibly coherent definition of the phenomenon is Robert McGrath (McGrath, 2003): A data format is a method for representing data in a digital store so that the intended meaning can be accurately reconstructed.

McGrath nevertheless makes a point of adding that a data format is both a model of the (potential) data representation which is inherent in the structure of the format, but also a mechanism for describing these data, that is, for describing concepts of the data model to digital objects such as files or memory, *metadata*. The central data repository notion, referred to by Mueller as a “data spine”, with the implication that there are no “crucial formats”, but that metadata governs the extraction and distribution of information, is another interesting outlook on why formatting is important to collaboration. For example, an XML markup can contain pointers to external data including binary files, in other words; a description of how to get the data, rather than the data itself (McGrath, 2003). What is to be examined then, is whether standardization as a principle touches on these representation and description mechanisms only, or could conceivably entail standardized methods for creating and manipulating data, as prescribed by the tools practitioners work with. Hence, there are two differing approaches to standardization; one is dictated by syntactically legible data, facilitated by metadata, for example in XML, to convey information, as outlined by Mueller: *"…Open formats will be automatically analyzed and semantically mapped from one to another. This means that the shared schema could be automatically constructed and extended, rather than being created by human-driven dogged-down consensus processes which tend to be very complex and will progress very slowly…"*

The "other" standardization approach necessitates not only conveying information, but assessing how this information is created. This is also fairly common in the AEC industry; we need only to look at the many standards, norms and best-practice instructions that are in place already. Therefore, it must be in the intersection of the 1) standardization of tools (e.g. formats and work flows) and 2) the numerous building regulations, norms, instructions and recommendations on how to design high-quality projects, that standardization will become feasible. Moreover, the combination of these factors already exists, too: Pre-configured parametric objects, such as "families" or "Library parts". The pre-configured as well as the user-configurable parametric objects can both hold attributes on the two conditional requirements to standardization, the meta- as well as the actual data. Hence, standardization of both actual data creation and metadata can be incentivized by how the objects interrelate through their respective design parameters, because this will produce much more enriched building models, in that it will allow for every contributor to use their favorite tools and correlate the findings with other team members' data. The one barrier is the lack of a coherent universal format, which will not obstruct the flow of information or suffer data loss. This infers: Interoperability is one of the main factors of collaboration. Formats must contain the method of representation, the mechanisms for describing data, as well as instructions on how to attribute data to objects with respect to constructability and best-practice norms, the process by which data are created.

2.3 Constructability and other Success Measures

This chapter is about the incentives of the building industry at large to promote optimization of architecture, engineering and construction projects and processes, with the design stages as the primary catalyst.

2.3.1 Value creation with constructability

"Profit is the inevitable conclusion of work well done" –Henry Ford

Traditional design processes are based on an activity-centered mentality for cost-saving, in which each activity is improved in disconnect to other activities, confined instead of integrated, which, as a planning methodology, may not fully reflect the involvedness of various project stakeholders or contractually specified tasks (Bejder & Olsen, 2011). One method which has been hailed for its optimization principles is Lean Thinking, in that its principal focus is not on savings on the bottom line (cost reduction) only, but also on value enhancement, in getting the most out of whatever existing capacity a company possesses (Waddell, 2011).

A primary success measure of a project is how practically accurate and executable its planning efforts are (constructable), but other performance indicators may be defined as well (Chan, 2001). The table below outlines how the various stakeholders assess a construction project, directly linked to a more trade-specific value judgment and objective/subjective success measures:

Performance Indicators	**Assessment responsibility**
Time consumption (objective measure) Cost (objective measure) Number of errors and omissions (objective measure) Building performance (objective measure)	Client, designers and contractors
Quality/functionality (subjective/objective measure)	Client, designers and contractors
Stakeholders' satisfaction (subjective measure) Efficiency and utility (subjective measure)	Designers and client

Table 2, Objective and subjective success measures, (Chan, 2001)

Designs may be analyzed and checked, but the software technologies do not facilitate checking for "pure design" (form) errors, as in the aesthetic/satisfaction-oriented/human success measures. In the BIM design process however, assessments of the following, and more, may be facilitated (Laine, 2012):

- Scope of project
- Content creation
- Milestones (When does auditing/combinations of models occur?)
- Quality control and compliance checking
- Specification of contractual requirements
- Constructability

As this document deals with creating value (meeting success measures) for the collaborating company, a set of generic “success dimensions” (Sadeh, Dvir, & Shenhar, 2000) i.e. the goals that are being pursued, should also be defined, and entail meeting design goals in relation to:

- Functional specifications
- Technical specifications
- Schedule goals
- Budget goals

Meeting these design goals can aid in providing benefit for the organization, in the form of relatively (as opposed to universally) high profits, the development of new technological capabilities, as well as benefits to end-users.

So, the objective is to move from estimates to analyses and calculations, a move to actual constructability assessment reports. Whatever values are to be found in a relational database can generate reports/graphs/clash detection reports, etc. These constitute vital transitional products, which may not count as deliverables, but will certainly facilitate the design processes and the realization of any project, because of improved communication.

A price-database link from the collaboration modeling platform should be established from the get-go (at model-creation), allowing the analyst to explore and compare versions of the project. For example, Location Based Scheduling and takeoff methods let the analyst see potential cost/time reductions. As previously stated, there are three modifiable factors to work with the scheduling and consequential duration of a project: *Production factors* (risky to use), *Crew* (number of members –faster/slower execution) and *Consumption* (up to the client).

Constructability thus equals value-creation in the AEC industry, because it is a prerequisite of successful project completion and sustaining future growth in responsible, waste-reducing ways.

2.3.2 A practical method of meeting goals in Design-Build

One technique which promises to alleviate the apparent lack of integration between stakeholders in AEC processes is Target Value Design. It is a management practice which could potentially reduce waste and rework, by reducing buffers in the project to spur innovation, or “self-imposing necessity”. That is, to impose constraints on the process as design-drivers, to evaluate designs against targets and make decisions at the last responsible moment (Ballard, 2012). This means carrying design alternatives far into the process and thereby having several design-sets to generate the best solutions. Instead of estimating based on a design, practitioners can design based on estimates. Instead of evaluating the constructability of a design, practitioners can design for what is constructible (Howell; Macomber; Barbaeiro, 2007). The following quote serves well to illustrate the point (Howell; Macomber; Barbaeiro, 2007):

“TVD offers designers an opportunity to engage in the design conversation concurrently with those people who will procure services and execute the design. (…) What do we mean by design conversation? We hold design as principally a social activity. The notion that some one person sits alone and is inspired to design misses both the nature of design and the countless contributions from others. The point of design is to bring forth new value in line with the client’s interests. What is value? Value is an assessment made relative to a set of concerns that someone wants addressed.”

The overall process can be said to have three main phases (Ballard, 2012): 1) The business planning, in which the allowable cost for a facility is set by looking at the business case, its acquirement costs and the lifecycle costs. 2) The feasibility study, in which the value-delivering facility is described, key members are identified, building performance is analyzed/simulated and funding takes place, provided that the scope of the facility is supported by the validation. Finally, 3) the design development, in which Target Value Design teams are formed by system (e.g. the structural, HVAC or façade system) and a target cost is allocated to each team, a set based approach is used to produce design alternatives and teamwork is promoted by having designers get input on costs, before developing design options. In these three main steps, the so-called *Cardinal Rule*, stipulating that the target cost is never exceeded, is a main driver of design, because if costs increase in one place, they must be reduced elsewhere. This approach to design eliminates “scope-creep”, where the extent of design-services is increased because of a technological capacity, and favors the assignments specified in the business plan and feasibility studies techniques.

2.3.2.1 The practice of Target Value Design

Here are nine "foundational practices" of Target Value Design (Howell; Macomber; Barbaeiro, 2007), which become especially relevant in the Design Development phase of TVD:

1. *"Engage deeply with the client to establish the target value"*
    a. Sharing responsibility for assessing what is valuable and ensuring the production to those values.
    b. Sharing responsibility for how the design is produced.
2. *"Lead the design effort for learning and innovation"*
    a. Making sure that advances in innovation and learning are documented.
    b. Re-planning according to this innovation, if necessary.
3. *"Design to a detailed estimate"*
    a. Evaluating a design against target values of the client.
    b. Showing these reviews to the team.
4. *"Collaboratively plan and re-plan the project"*
    a. Planning together to coordinate action.
5. *"Concurrently design the product and the process in design-sets"*
    a. Developing details in batches together with the recipients (other stakeholders).
    b. Validating details against the work of others while the design work is being done.
6. *"Design and detail in the sequence of the customer who will use (your product).*
    a. Maintaining attention to what is valued by the client.
    b. Reducing negative iteration.
7. *"Work in small and diverse groups"*
    a. Communicating and coordinating to establish exchange- and trust based social dynamics.
8. *"Work in a big room"*
    a. Co-locating to ensure trade7consultancy specialists exchange their views.
9. *"Conduct retrospectives throughout the process"*

2.3.3 Preliminary Conclusions based on Literature Review

This chapter deals with the literature reviewed, to see how the three domains of strategic tension in planning and design influence each other. In its approach to the case studies this project will attempt to determine how the actual can-want-need deviates from the theoretical can-want-need. This is the basis of formulating a value creation strategy for Design-Build management.

2.3.3.1 Strategy formulation guidelines

A business strategy should be translated into short term operational goals for departments and individuals. Therefore, clarifying responsibilities on all organizational levels is a prerequisite for strategy implementation. The successful execution will revolve around managing change in the early stages and providing valid feedback to monitor performance metrics in the long run.

2.3.3.2 Evident advantages of Design-Build integration

As the theoretical advantages of integrating Design-Build projects are explained in-depth in the prior chapters, this will be a bulleted list:

- *Can*, individual level
  - More informed decision base.
  - Possibility of obtaining information when relevant, in relation to milestones.
- *Want*, firm level
  - Interoperability for trades and departments, basis for relevant quality assurance.
- *Need*, industry level
  - Structure for delivering projects on time and to cost.

2.3.3.3 Evident obstacles to Design-Build integration

- *Can*, individual level
  - Many different working methods prevail, for every trade and individual.
- *Want*, firm level
  - The work of different trades can be difficult to view as a collaborative whole.
- *Need*, industry level
  - Conveying the need for clients and the industry to engage in integration requires time and effort.

3. A representative sample of BIM/ICT/VDC in Danish design firms

As integrated practice is inherently inclusive of all disciplines represented in the industry, an assessment of implementation and performance through BIM and ICT, at a general level in “design firms”, is needed. This is relevant because of the direct link between a design team’s scrutiny and quality assessment of its project material, and the constructability of a project for the contracting firm commissioned to the task of building it, ultimately for a client’s benefit.

This sample was taken at a kick-off conference for ARK|BIM, a recently initiated trade organization for design firms using “architectural BIM” in Denmark, with an emphasis on digital technologies in architectural practice, on Nov. 14th, 2012, at the Royal Academy of Fine Arts, School of Architecture, in Copenhagen. The objective of the anonymity of this account of the conference, in the context of a student publication, is to ensure that none of the firms/speakers are identified by name and to provide a holistic narrative of the talks.

Common for the firms presenting their work is that all of them are currently working with merging and querying models from various consultants or trades. This does not seem to have had an impact on the organizational culture of any of the firms. It can therefore be deduced that the implementation, on a broad scale across the represented companies, has set out from the technological tool-perspective, instead of an organizational perspective. All the presenters showed works that have incorporated a parametric/computational design approach to some degree, even if this implementation has been affected by general skepticism in its early stages. All speakers seem to agree that “good architecture” does not arise from the medium or tool being applied to a problem, but through increased possibilities of consistency-checking, auditing, coordination, automation and visualization/communication. These possibilities for adding value to a project still does not imply full design automation, such as engineering an algorithm to compare two or more variables in a set of rules governing a specific design, e.g. like (Furhmann & Gotsman, 2005) outlines in the following paragraph, (not made a note of at this specific conference):

“The architectural design process consists of several components. A set of rules describes the set of all valid configurations for a given site. A measure function assigns a figure of merit (a `score') to a given configuration. An efficient algorithm for searching for a configuration with the highest merit among all valid configurations is then required.”

Although what “good architecture” means under the circumstances did seem highly subjective for all speakers, one of the talks brought up a point which does add perspective, from a qualitative point of view:

“Is design the vehicle for technology, or is technology the vehicle for design?” In this case, the architect in question much preferred the first of the two options. This bears the implication of technology being resisted as the facilitator of consultancy in building project, for the sake of the facilitation alone. Tools are seen as media, assisting the work of the individual’s design method. However, when the work gets co-creational, collaborative and trade integrative, when a 3-dimensional model of the project has been built and the other stakeholders in the process are to be involved, it seemed only a few of the represented firms had updated their individual methods to accommodate to the need for trade-integration. That is, only a few of the projects shown had been committed BIM-projects from the outset. It was clear from the presentations that everyone recognized that information is valuable only to the extent that it facilitates or strengthens a basis for decisions about the solutions in a project. Therefore there was a broad consensus that the architect’s role is not to add more data than necessary, but to work in spatial configuration (geometry), assigning functional parts (quantities) and provide an overview of the building design in question. Another important point from the perspective of the AEC industry in general, on the subject of quality assessment of the digital objects, as well as how these interact in virtual buildings, is that architectural designers has been used to assessing designs from a visual standpoint and therefore the numerical values of the BIM objects demand a different kind of scrutiny. This, evidently, is an important part of quality assessments, because for architects/designers who have been used to a traditional approach, informed primarily by 2-dimensional drawing, a 3D object becomes difficult to assess, in that it will seem finished, worked through and production-ready, even at very early stages of design, because traditionally building parts were seldom rendered in 3D from the beginning of the design process. Drawings informed other drawings, which in turn generated 3D views. It can therefore be challenging to decipher what stage of refinement a given design solution is at, if it seems completely clarified and cultivated to the point of production-enablement. Additionally, it seemed as though there was a consensual idea of selection criteria that will ensure the livelihood of designers in the future: ICT-competencies are recognized as an absolute prerequisite for survival in the industry at large. One

of the key stages in which this will manifest is in digital tendering, on the basis of design, implying a digital work flow throughout all the preceding phases.

3.1 summary of conference

The status of the represented firms, on the day in question, can be indicated in a bulleted list:

- Architectural designers are currently fighting for survival in an industry which is abandoning the ways of design that have traditionally been the domain of architects/designers, in a “digital age”.
- Architectural designers, indicated in the sample represented, *seem* to want the architect’s role to orchestrate every step of the building design processes, and *seem* to understand their specialty as the only trade advocating or working towards aesthetics (as in, the study of sensory-emotional values) in building design.
- The architects present at the meeting were in consensus that *“everyone in the industry”,* (specifically contractors), want to ascribe the first phases of building design to their particular services, effectively taking the work of the architects upon them. This is quite contrary to the tenets of integrated practice through BIM/ICT/virtual buildings (Deutsch, 2011).
- The extent of technological implementation in the architects’ trade in general has reached its peak in computational/parametric design, with the main competition-parameter being sustainability (energy consumption/resource use management).
- Another implementation under way, deemed no less important by the attending professionals, is that of the ICT-agreements on the cases they are working on. The importance of specifying the contractual basis in relation to the tools used is recognized.
- The adoption of “new” technologies is largely dictated by which generation a given practitioner represents.
- There are vast differences in how relevant terminology is used in the various firms, and one of the primary strengths of ICT, quality assurance, has no collective guideline ascribed to it. When quality assurance is used, it seemed it was for auditing one’s own services more so than securing dispatch control, i.e. when sending information to other stakeholders in the process.

3.2 Future applications of BIM/ICT in Danish design and construction firms

- Concurrent Design Practice

This qualitative sample was taken at the research symposium **"**Confluence - Establishing data flow from Design to Site", with an emphasis on digital technologies in architectural practice, on Nov. 23rd, 2012, at the Royal Academy of Fine Arts, School of Architecture, in Copenhagen (CITA, 2012). One of the primary inputs to this chapter comes from a talk delivered by a representative of Gehry Technologies Europe, Tobias Nolte, an engineer from Berlin. The parts of this chapter reflecting on that specific talk should be read as an interpretation of the delivered speech, not a summary. The relevance of this chapter is the collaborating company's decisive move from a purely production-based organization to also encompassing knowledge-based services. The chapter will contribute to the company's knowledge base in that the sample is very recent and the subject matter was comparatively "cutting-edge". The illustrations/images in the chapter were *not* acquired at the conference.

The term complexity is generally put to use to describe something with many parts in intricate order. Complexity is a circumstance which emerges from an assortment of interactions between things and/or concepts.

There are two types of complexities in Design-Build projects (Nolte, 2012): one is an organizational/institutional complexity which arises from the coordination of activities and the resources (people) carrying out the activities. The other is the formal/structural complexity of a project in itself, which arises from the demands, constraints as well as the technical and spatial configuration of the prospective facility –as that of a building, for example. These two types will henceforth in this chapter be referred to as "process" and "product", respectively.

In the management of these two types of complexities, certain disciplines generate an overlap between the two, essentially allowing process and product to accommodate to one another, exemplified in the following four points to be made on managing complexity:

- **Model management** is central to VDC/BIM in that it specifies both responsibilities to interact with a proposal and the interactions in and of themselves, encompassing both organizational and structural complexities.

- **Modular processes**, such as 4D-sequencing on the temporal scale of the product's realization, lead to rationalization and coordination of both the process and the product, since interdependent work on the model can be structured to reflect the work on site.
    - In surveying and in quality assurance, the two types directly manifest, for instance in clash detection in 3D models and upon inspecting work on site.
- **Optimization.** E.g. drawing production; conceptually as well as fabrication-oriented, the more automation a company achieves, the more dimensions may be integrated into the design work, cf. Jerry Laiserin's graph below (Laiserin, 2008), and the less time will be spent on graphical work. This means that tangible design parameters could theoretically be treated with higher priority, than a representation of the product.

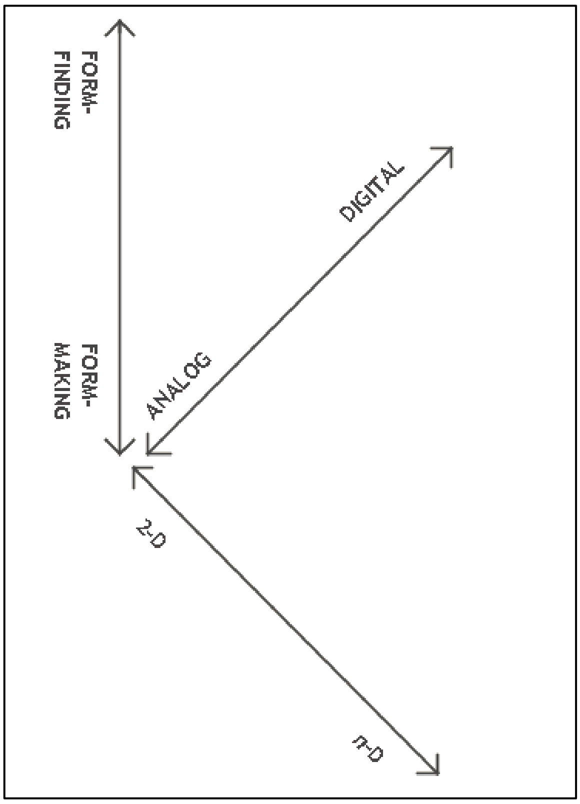


Figure 21, Form-making vs. form-finding, (Laiserin, 2008)

- **Access.** The size and complexity of large datasets necessitates a rethinking of how the model is represented, since unified representation holds inherent problems:
    - A centralized information repository does not necessarily dictate a centralized access to this repository -on the contrary- since not all trades will access all data.

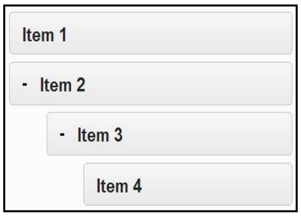
3.2.1 Four points regarding complexity management in Design-Build

The **Model Management** point of the aforementioned disciplines must be: *Integrated*, a central model with decentralized access, *Pervasive*, securing the unified contributions to the project, *Fast*, ensuring lead-time reduction through shorter cycle times, *Transparent*, not too complex to understand for users and *Automatic*.

The **Modular Processes** in VDC/BIM generally include universal parts, much like the modular, prefabricated parts of buildings that are so common today. In one of the currently most widespread authoring tools, these are known as "families". Like its management, the virtual building must also be *Integrated,* that is, combining separate elements to provide an interrelated whole, and these separate elements must be *Batchable,* or *allowing the grouping of modifications in batches.* This entails that a "batch" is a series of changes to objects in a model, and the term "batchable" refers to the set of methods that a class/object must have implemented, to allow persistence of the data store in a batched manner, as opposed to individual object saves (ServaSoftware, 2012). In other words changes and modifications can be made to many objects at once, provided that the objects belong to the same class, object or "family". Batches can be nested. Changes in nested batches are applied only after the most enclosing batch is terminated or saved. Therefore, overall processes must be *Nestable.* "Nestability" is best exemplified with illustrations like the following (Bushell, 2012):

Here, nested objects are shown in collapsed list-form, creating this serialized output:

[{"id":1},{"id":2},{"id":3},{"id":4}



Here, nested objects are shown in exploded list-form, creating this serialized output:

[{"id":1},{"id":2,"children":[{"id":3,"children":[{"id":4}]}]}

These are from Javascript, but serve to illustrate the concept of nesting as applied to computational models, as the principal hierarchy. Moreover, it classifies the objects ontologically, without user-intervention.

The **optimization** efforts must approximate solutions between the geometric constraints, budget constraints, site constraints, fabrication constraints and installation constraints of the given project, working towards an integrated optimization of the planned building as a whole. This is called "parametric convergence" and signifies the achieved equilibrium between all the factors at play.

Some form of a balanced compromise will be found to exist between the modular efforts and the optimization, however, because the more dimensions we include in our projects, such the aforementioned constraints, the more that project will be built "from scratch", as opposed to applying fully standardized solutions in the feasibility studies and concept development stages of building design.

The **access** to the model in a VDC/BIM design process, which has as much to do with data security as it has to do with user-convenience, can be obtained through online collaboration.

Access should be achievable from any browser, include messaging from one party to another, should support industry standards to be able to read models from different authoring tools, should support file sharing/synchronization, security settings and auditing/administration solutions.

3.2.1.2 Accommodating to the complexity of Design-build projects

Tobias Nolte of Gehry Technologies made a point of showcasing "G-team" (GehryTechnologies, 2012) at the conference, an on-line collaboration platform which does all those things. It is essentially a file-sharing project web solution with strong graphical capabilities to show thumbnails, previews, displaying sections, take measurements, annotate in the model and even conduct clash-detection within the cloud based interface.

Aside from providing 3D model viewing, any authoring tool can be used, which could potentially optimize consensus-based processes, because of the social networking characteristic of the application, with user profiles for every project. This also facilitates portfolio management, because stakeholders can join many different projects at a time.

4. Methodical approach to cases studies

Firstly, it must be emphasized that the principal academic scope with regards to the specific types of contractual arrangements in this assignment, is going to be, above all; how to search for ideal solutions to the issues faced by this organization and by the industry in general. Secondly, that this thesis-project deals with all creative and technical design stages of construction projects, *"projektering",* as it is known in Danish, without favoring one phase model. Thirdly, the identification of potential improvements is paramount to this study.

From these points of departure, a comparison with empirical case-registrations will form the basis of analyzing the gap between the "ideal" and the factual. This approach is taken to validate the theoretical research by relating it directly to a case, on which research could be conducted and compared to the principally ideal picture of the theoretical study. By doing this, an analysis of the barriers and obstructions, as well as an uncovering how much of a "gap" exists between theories and practice, can determine how to obtain a focal point for optimization efforts. The identification of these measures will be treated in chapter 4.2, *Analysis methods.*

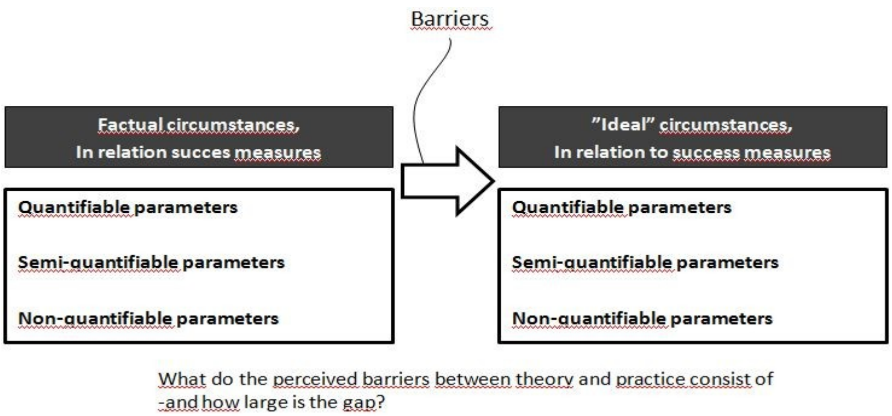


Figure 22, Approach to research: The comparative study of theoretical and practical measures, by the author

To underline the educational goal: the scholastic process which will come to fruition as this thesis report, should gain a capacity to act as an objective commentary. Also, as a potential long-term secondary function, as a methodological approach for the design and specification departments of the organization, to supplement established routines or aid in redesigning routines. It appears critical that design processes be controlled in a way that takes sufficient account of the increasing intricacy of construction projects, the varying organizational structures of clients and users - functional as well as technical, a growing number of trade-specialists, and the tenable need to boost efficiency and quality. This forms the rationalization behind doing this academic project, combined with the contextual challenges of the industry.

4.1 Purpose and scope of the methods in this document

The purpose and scope of the methods presented is to show how to capture a valid set of data that may be put to use in analyzing the planning and control efforts in the design- and specification stages of a Design-Build project. Arguments for selecting the specific methods are presented under each chapter, dealing with specific means of analysis, in the framework of the case. The relevant situation in this case would be the organization's ongoing commitment to carrying out design and construction projects and the company's strategy in the future. No company-specific organizational strategies will be dealt with in this report, as the company's anonymity could be compromised. Forward analyses on both empirical and theoretical bases –in an effort to, as a student, contribute to the organization– will be presented in the form of recommendations at the end of this assignment. The specific methods have been selected for their ability to be combined with one another (each of the techniques can be combined with the others, to provide a comprehensive picture of the situation at hand). The selection is also based on the methods' apparent abilities to communicate to both immersed subjects, as well as objective readers.

4.2 Analysis methods

After the identification of relevant cases to which the methods may be applicable, there are many ways to go about an analysis of the work flows and information exchanges of a company, by way of conceptual modeling (Svidt, 2010). On a basic level; free-sketching, mind maps, synopses and so-called rich pictures can give the researcher an idea of the subject, and convey his/her ideas accessibly. For functional modeling and process modeling, the IDEF0 standard is a well-renowned method, whereas product- and structure modeling may require IDEF1/X modeling or an Entity-Relationship model, to communicate a representation of a system, whatever that delineation may hold.

4.2.1 Case 1

A large scale renovation project:

- Design-Build project, *Methodical approach: Immersive/ethnographic, semi-structured interviews.*

As a combination of process and product modeling, the Unified Modeling language, UML, and Contextual Design Modeling, CDM, can carry and transmit information regarding systems, and describe complex systems in their entirety, due to the several abstractions of a subject that may be assumed. One technique couples these functionalities: The methodical approach to this project will start with the systematic technique of Contextual Design (Beyer & Holtzblatt, 1997), hereafter referred to as CD, which is actually a method to conduct research as the basis for software/interactive systems development. The objective of any conceptual modeling approach is to determine where a topic can be elaborated qualitatively or quantitatively, to refine said topic. It is claimed to be faster and more reliable than ethnographic studies (Preece & Rogers, 2002) and is a method that allows developers and change-agents to convey to users or workers exactly how their routines will change. In this particular research, it will be the beginning of the analyses of work flows on a specific case, which utilizes the Design-Build arrangement, in the organization.

4.2.2.1 Abstraction and modeling approach

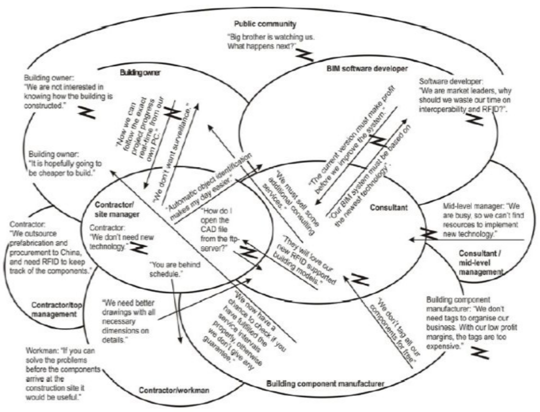


Figure 23, Cultural Model in CD, (Birch, Svidt, & Christiansson, 2009)

The work environment either enables or inhibits the tasks and activities to be performed. The *Cultural Model* is one conceptual abstraction from CD serving to illustrate cultural influences and assertions that agents may demonstrate, in relation to each other. In figure 8, the “bubbles” show users or agents with overlapping interests, and arrows illustrate cultural influences. This analysis is decidedly qualitative in its approach.

4.2.2 Case 2

A commercial development for a corporate client:

- Design-Build project

Methodical approach: WBS, Contextual design, structured/semi-structured interviews.

4.2.2.2 The Work Breakdown Structure

The Work Breakdown Structure, henceforth referred to as WBS, is originally an approach to validated budgets in construction, through the decomposition of a project that defines the discrete constituents of its hierarchical formation. It works by a tree structure subdivided into as many parts as is seen fit. Each activity on a project may be assigned to its practitioner, and so the functional or financial requirements to one particular subordinate activity are designated to the activity by the practitioner him/herself, after which the decomposed parts, known as *work packages*, generate the full view of the tree-structure of the project. On this project, it will not be applied to budget validation, but will be used as data collection method, see figure 9.

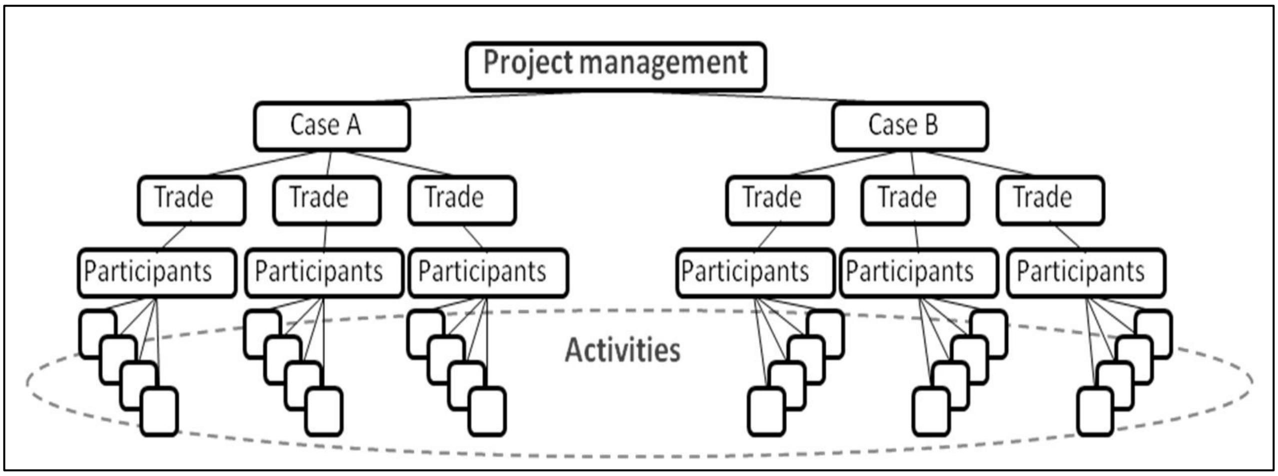


Figure 24, The Work Breakdown Structure principle, by the autor

In collaborative (integrated) design, the processing of information will not be serial or linear, but can be expected to take the form of parallel processing, or follow concurrent engineering principles **(Pouchard & Cutting-Decelle, 2007)**. This necessitates some form of numerical/ontological structure, since, as previously argued, no apparent phase-arrangement is formalized in Design-Build, and therefore the WBS can provide a framework for the delegation of tasks and activities, over the course of the project. The inter-relational system that is the construction project can be organized through WBS, because each work package has a unique identifier, and any kind of syntax may be applied. This is made possible by the same principle that decomposes the structure of the project: that the people responsible for the tasks get involved in planning activities with a project team. This seems to correlate entirely with the configuration of

Design-Build projects, in that everyone on board the project contribute constructively to the process, with their knowledge and technical skill.

4.2.3 Case 3

A business model for Design-Build, in an international context:

- Strategies, marketing, team formation, etc.

Methodical approach: Structured interview.

4.2.4 Output of methodical procedures

As the product of these aforementioned methodical approaches, the state diagrams can be constructed as the basis of the planning of design and specification efforts on a Design-Build project. To properly suggest a sequence of contributions by the implied stakeholders, it must specify actors, tasks, milestones and data transfers between stakeholders on a tactical level of the project, as well as participants in the activities on the operational level of the project.

One eminent feature of the WBS is that it does not emphasize an organizational hierarchy, but simply shows participants, responsibilities and information transfers. Additionally, a time scale will be shown, but it is not a time planning tool per se, it rather forms the basis for best-practice guidelines, one of the formulated goals of this academic project. This accommodates well to the Design-Build arrangement, because it too, does not merely emphasize an organizational line of authority, but also an approach–oriented participant selection (Lahdenperä, 2012).

The notation is thus compliant with the contractual basis of such a project (through defined activities and deliveries), and can be coupled with other planning tools such as network planning and the like. In addition to the methods suggested, interviews of participants will supplement the collected data to provide more qualitative bases from which to draw conclusions and make recommendations.

in consequence, the methods are selected to facilitate the conclusions and recommendations part of this report, in which the research problem is to be answered.

5. Case studies

5.1 Case study 1: Large-scale suburban Design-Build renovation job

This case is included in the report at hand to obtain a perspective of the Design-Build methodology both as a catalyst for physical change in a building project, but also a catalyst for organizational change, in the group effort of large scale projects. In this case, the practicality of conducting design-review and project scrutiny meetings between the collaborating company and their subs, both design/engineering professionals and builders, was the main grounds of motivation to conduct an analysis. A large number (500+) of attached and semi-attached row-houses are subject to an on-going renovation in a Copenhagen suburb, the collaborating company as the Design-Build contractor has overseen design-management, with the service of design and detailing subcontracted to an architecture firm. A job site consisting of 57.000 m² of floor-area refurbishment is a very large task, for which not only a comprehensive procurement method must be in place, but comprehensive team-working efforts are to be planned. Because the project entails new roof and wall structures, new active mechanisms/piping/ducting, new connections to public supplies, retrofitting insulation, new windows, façade cladding, solar panels and landscaping, the design-coordination is imperative for the holistic planning of the row houses. This leads to specific challenges faced by design/project management.

Figure 25, photo collage, photo courtesy of collaborating company, elevation drawing from architect's website

5.1.1 Challenges faced by the design management on the case

This cross-sectional interpretation of the challenges faced by the design-management on the case was conducted at an interdisciplinary design-meeting. As the issues surfaced through dialogue, notes were made to convey them in a bulleted list. Challenges included:

1. *Mitigating interactions between the trades, the technical solutions to construction issues and the selection of specific building elements that must comply with the demands of the client, and the relationship between these factors. Not having an ICT-agreement specifically attuned to the project, causing the agreement to be criticized –undermining digital collaboration on the case.*

2. *Discussing alternative solutions to issues, with respect to the flexibility of the finished buildings.*

3. *Choosing suppliers who's products comply with the demands to the finished project, while balancing the total cost of the project.*

4. *Addressing the renovation job through a modular approach, namely that of the contactor's own production/execution teams, while working with a project that may not sustain this approach completely, due to the nature of older construction.*

5. *Balancing local regulations and design intent, for instance the amount of candela from a specific streetlamp chosen for its form and tone of emitted light, which does not comply with the luminous intensity prescribed in the municipal regulations.*

6. *Obtaining concurrence (as mediated by the contractor), between the various trades and their priorities. On the specific case, an example of this coordination was the selection of a skylight solution: categorically, the architect favors aesthetics, the contractor favors constructability. Both these stakeholders are dependent on the climate-engineering consultant to make calculations of heat-transmission and energy consumption. The engineer, however, cannot make calculations without knowing the chosen product and construction. In the sequence of posing criteria and demands, the interdisciplinary design process must be coordinated to be a succession of tasks.*

7. *Although the procurement on this case is "officially" a Design-Build contract, the application for building permit only encompassed the architect's project, with the other consultants being added to the design process shortly before excavations on site, as a means to meet requirements to the buildings. Although the consultants and builders seemingly added an immense input to the case, the design project started deviating from the competition entry, the basis on which the case was won. This presented a problem for the architect as the formal designer and the obligations to the client organization, who, not surprisingly wants the project that was awarded the contract.*

5.1.2 Cultural Model diagram

The Cultural Model (Beyer & Holtzblatt, 1997) is an approach to analyses which intends to capture where the goals and objectives of different stakeholders may deviate. In this notation deviations are marked with a "**z**", and are all related to how much of a base for decision making the parties have. The statements indicate the nature of the problem: responsibilities are difficult to plan. They tend to emerge in the process, instead of being predefined, by the dependencies of the various parties on each other:

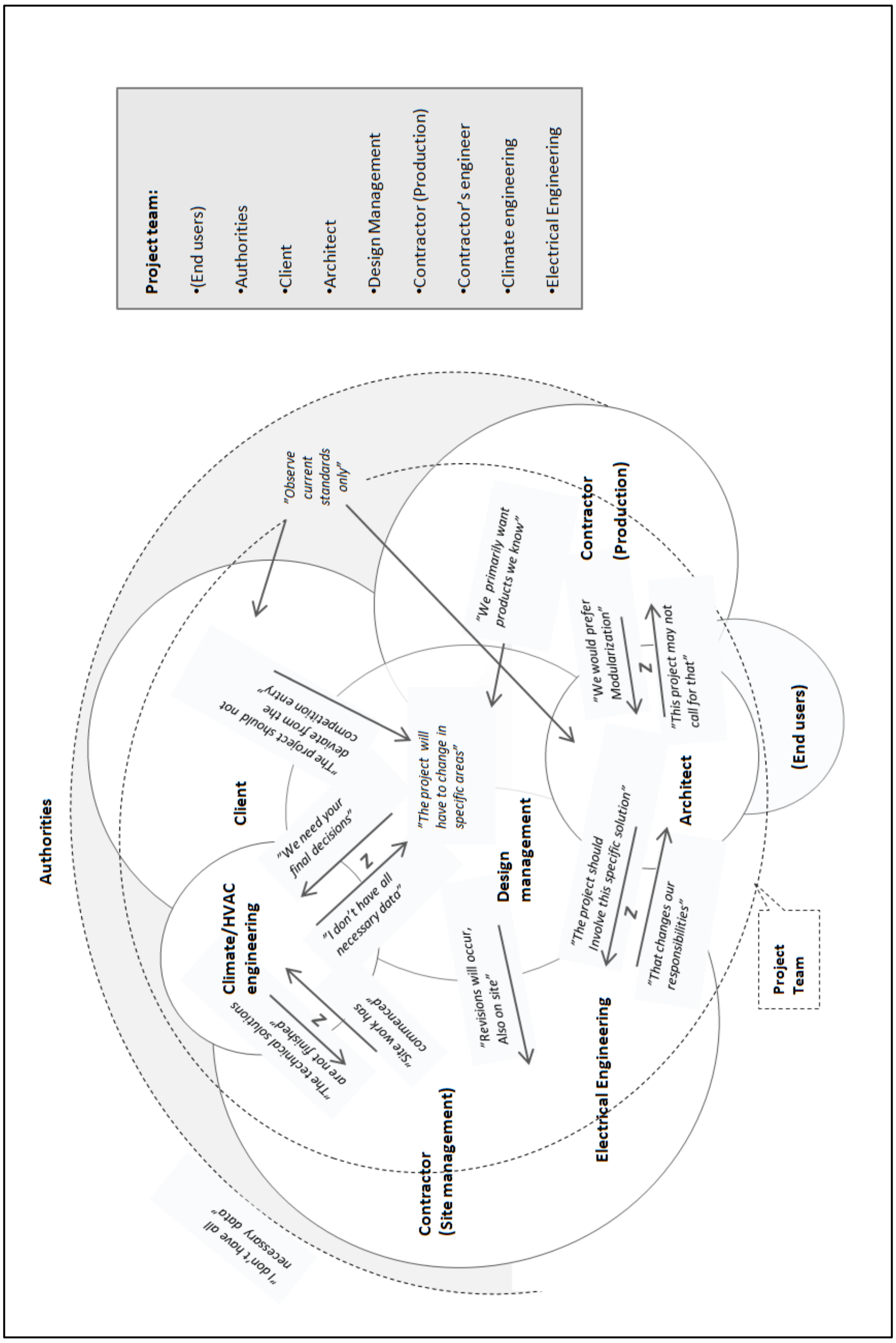


Figure 26, Cultural Model case 1, by the author

5.1.2 Responding to the challenges on the case

One management effort in particular, which required all participants to obtain a common focal point to optimize the given solution, was an installations-room under the stairs of the two story residences, in which all the active mechanisms of the building were to be placed. This triangular space accommodates to new installations, but also influences many other parameters; excavation works around wall foundations and stair foundations, the penetration of piping, the deliveries and placement of ducts, cables and radiators, to mention but a few things. The scrutiny effort, at the design-coordination meetings, was largely based on the 2D drawings of the various services and their interrelations, but was not centralized in one document, due to the complexity of the graphics –it would not be legible if all the aspects of the technical room were to be conveyed orthographically with line-drawings.

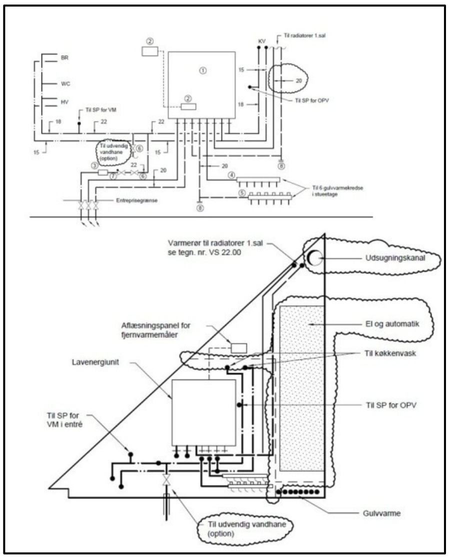


Figure 27, Technical drawing, courtesy of mechanical engineer, case 1

5.1.2.1 Conducting project scrutiny through 3D-modeling

A 3D model was prepared to gather the information in the drawings, as well as to obtain an interface through which the stakeholders could gather the information discussed at the scrutiny meetings, substituting the normal minutes-of-meeting approach to making summaries. 3D-scrutiny can assist the coordination of stakeholders through trade-models that show the integration of the different services in the building. It consolidates the efforts that need to be scrutinized, without changing responsibilities and liabilities in the process. Therefore, it did not have an effect on the contractual relationships in the project and was really only used as a visualization tool. The approach, therefore, was not a

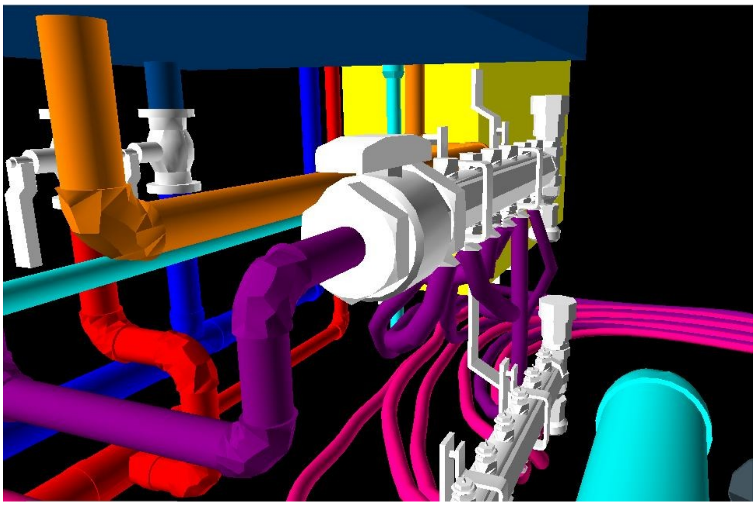


Figure 28, Screenshot of 3D model, by author

"full" BIM-process by any standard, but attempts were made to address specific problems in the coordination of the trades and consultants, which gives it factual merit in the context of this academic report. The summary of the meeting was not noted in the form of annotations directly in the model, so it became the motor for conversation, rather than an actual record. A collision-test in the model was carried out as well, showing the stakeholders where the various trades interfaced or clashed, both in the building parts and on-site sequences.

5.1.2.2 Challenges to conducting project scrutiny with 3D-models

Not all the relevant drawings to support the meetings were on the company's project web at the needed time, which may lead the secretary (or whoever takes minutes), to not make a full record of the proceedings, since only the material present was discussed. This inadequate sharing of information could potentially make attendees doubt the premise on which they are conducting the coordination. An apparent skepticism towards digital media was voiced or indicated by several attendees present. The demands posed to the model itself were arguably not exhaustive, but this depends on the level of ambition with respect to using 3D models. On this case, the management has not been overly ambitious, but was seen to accept and verbally endorse all the solutions proposed by the company's BIM-department.

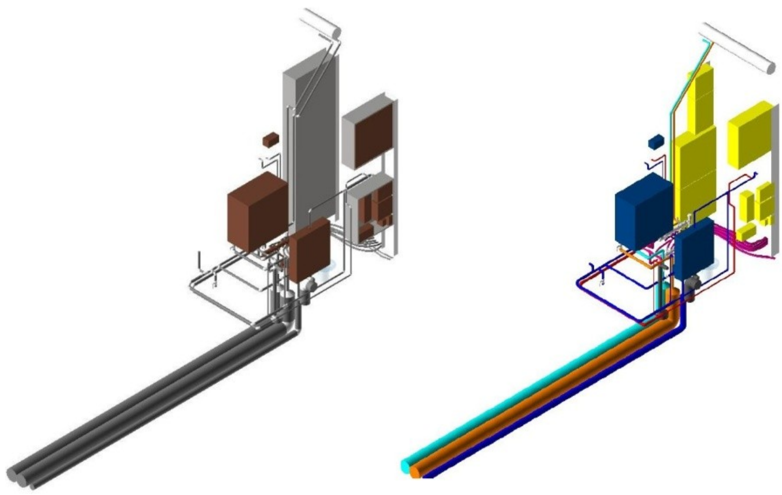


Figure 29, Model at different stages of the interdisciplinary scrutiny process

The meeting was primarily constructability-oriented: the principles, placement and level of quality of HVAC and electrical works and the assembly sequence of the elements on-site. This led to a discussion on time-planning and coordination of subcontractors. The question remains: Which arguments could justify the continuation and use of 3D modeling, in this specific case? Answering that question from a highly qualitative perspective; it provided the discussion with certain unidirectionality, in the physical act of looking at a screen. Everyone present observed the remarks being made, annotating specific instances of design solutions or pending questions, directly in the model. The focus that this provided for the involved parties was, in the words of the project manager *"convincing, quite possibly the way forward from this point on".* This came from an experienced project and design-manager who has seen many projects and interdisciplinary meetings over the course of a career, and who – also in his own words – is not a proponent of technology, for the sake of technology itself.

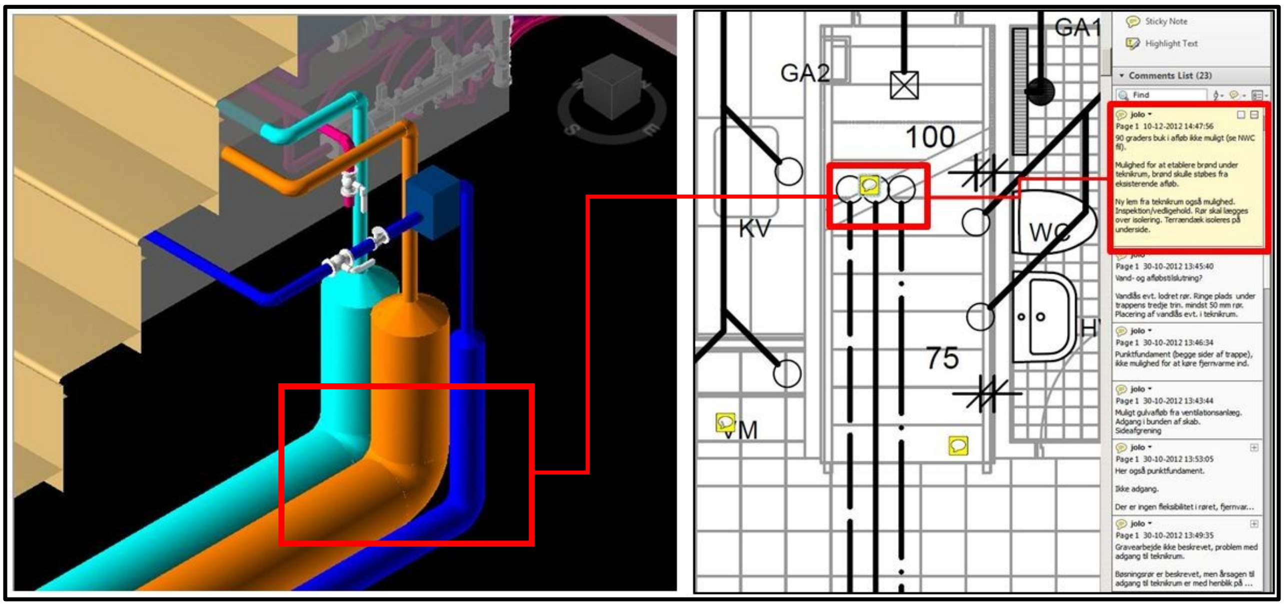


Figure 30, Screenshot, case 1, by author

As indicated in the image above, by the author, put together from two different screenshots at different stages of the work, problems were identified in the model, located in the drawings and subsequently any issues, along with the proposed solutions, were summarized in comments directly in the drawing. This was the preferred form, as the various consultants were not theoretically equipped to have their comments be summarized directly in the model, although this possibility was presented at the meeting. As the outcome of this process, the summaries of the project scrutiny were compiled in the construction drawings for the project:

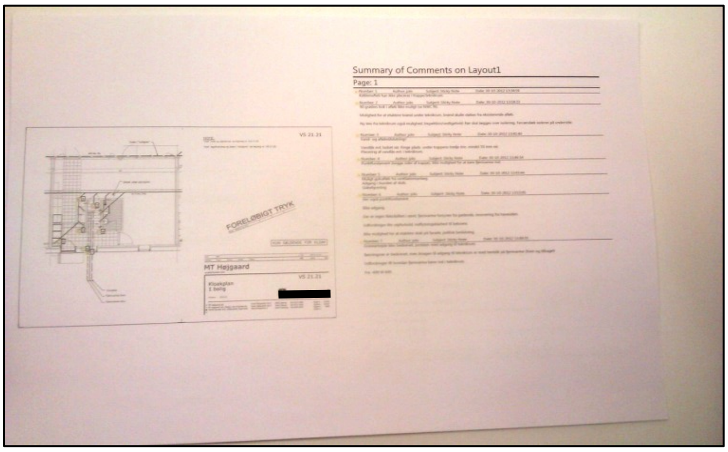


Figure 31, Summarizing scrutiny comments in working drawings, by the author (Company anonymous)

5.1.3 Conclusions, Case 1

The collaborating company has, apparently, had issues with arranging trade-interfaces in the design process of the renovation job. However, in several instances, the team members were able to contribute their expertise to constructability issues, so the project was in fact more integrated in reality than “on paper”. Integration was at work between the people present, but this method was not explicitly worded in the process. Although not revolutionary in any sense, conducting a trans-disciplinary design/scrutiny meeting by using a 3D model seemed like a foreign approach to some of the parties. Again, the focus that a 3D model provides is a commanding incentive to implement this relatively low-tech approach on every level of project and design meetings. In time, this approach may be fully implemented, eliminating paper-based annotations. It is not in a tool itself that advances lie; it is in how we use tools as a means to an end.

5.1.4 Recommendations to collaborating company, Case 1

The following recommendations have been made on the basis of the one case in question and should therefore not necessarily be interpreted as applicable to every project of the organization as a whole. It is a methodical handbook-approach to projects *like* the one in question. The next points are deeply related and divisions are artificial, made for the legibility of this conclusion.

5.1.4.1 Recommendations to work processes

The tools and the process are highly interconnected, but the process has been around long before the tool. This chapter has not attempted to measure attitudes towards using the tool, only to document the changes brought about. As stated, it was seen as an improvement. The recommendation is to keep pursuing the methods described and to keep refining them.

5.1.4.2 Recommendations to contractual engagement

Although this was “officially” a Design-Build contract, many of the processes seem to reflect more traditional ways of doing things. It was only in the meetings that integrated practice became apparent. Through the ICT-agreement the contract could reflect collaboration, which it did not.

5.1.4.3 Recommendations to application of technologies

Every trade should model their contribution *before* scrutiny, not *for* meetings, this is elementary. Having external consultancy for modeling projects is excessive, except for extreme complexity.

5.2 Case study 2: A commercial development for a corporate client

This case study revolves around a large scale project, the new corporate headquarters of a company based in Copenhagen. The project is comprised of approximately 50.000 square meters of office space, divided into two buildings, one somewhat bigger and the object of this analysis.

Figure 32, Project in question, photo courtesy of client organization's website

Since it is a relatively large-scale project, the focus of this assignment is to look at a representative flow of information and deliverables in the project, to 1), infer general conclusions and 2), to grasp the case within the constraints of this report. Therefore, the case study looks at prefabricated structural concrete elements and does not make its conclusions regarding the whole load bearing structure or every systems delivery of the project, as outlined in chapter 4.2.2. The timeline below illustrates the design elaboration of the structural prefab concrete elements, by the author:

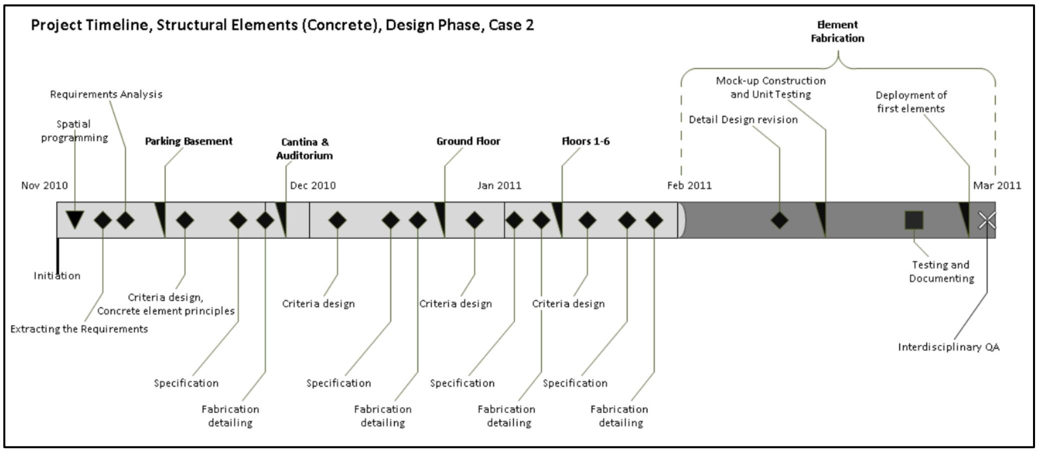


Figure 33, Project Timeline for concrete elements, by the author

5.2.1 Selection of a representative flow

Addressing the concept of minimizing waste in Design-Build deals with the project's degree of integration, because that is the basic means to drive this contracting form. Hence, the primary criterion for selecting one flow of information is that all stakeholders are present in the process. Looking at the work breakdown structure, one clear choice is the structural core. It is made up of prefab elements, it is contributed to by every stakeholder and it impinges on the entirety of the building process, in design and on site. The diagrams are produced on the basis of time schedules acquired from the design team (architect, engineers and supplier). The stakeholders involved and their tasks are shown in the diagrams below:

5.2.1.1 The work breakdown structure, Activities

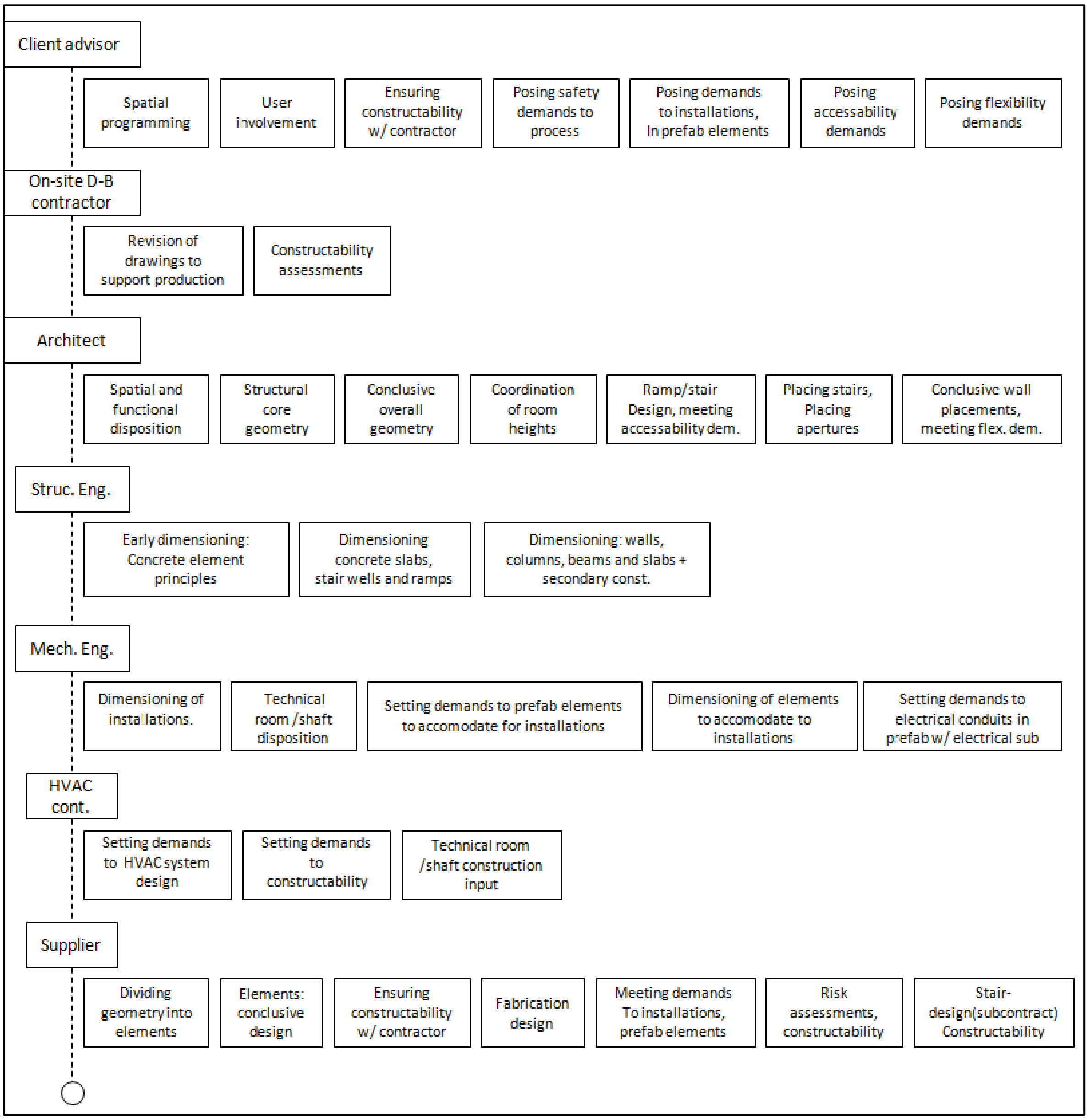


Table 3, WBS, activities, by the author

5.2.1.2 The work breakdown structure, Zones

The work breakdown structure (table 4) is shown here as a table instead of a tree, on account of the repetitive nature of design work associated with prefabricated elements. Only tasks related to prefab element are shown, organized by functional zones of the building as main delivery points.

Zone	Client advisor	On-site contractor	Architect	Struc. Eng.	Mech. Eng.	HVAC cont.	Supplier
Substructure							
Parking basement Tasks pertaining to the design /specification of prefab structural elements (concrete)	Spatial programming. User involvement. Ensuring constructability w/ contractor. Posing safety demands to process.	Revision of drawings to support production. Constructability assessments.	Spatial and functional Disposition. Structural core geometry. Ramp/stair Design, meeting accessability demands.	Early dimensioning: Concrete element principles. Dimensioning concrete slabs, stair wells and ramps	Technical room /shaft disposition. Setting demands to prefab elements to accomodate for installations.	Setting demands to HVAC system design. Technical room /shaft construction input.	Dividing geometry into elements. Meeting demands To installations, prefab elements. Fabrication design. Elements: Conclusive design. Stair-design(subcontract) Constructability.
Superstructure							
Cantina Tasks pertaining to the design /specification of prefab structural elements (concrete)	Spatial programming. User involvement. Ensuring constructability w/ contractor.	Revision of drawings to support production. Constructability assessments.	Coordination of room heights. Placing stairs, Placing Apertures. Final wall placements, Meeting flexibility demands	Dimensioning: Concrete element principles. Dimensioning: walls, columns, beams and slabs + secondary const.	Dimensioning, installations.. Dimensioning of floor elements to accomodate to installations	Setting demands to HVAC system design. Technical drainage system construction input.	Dividing geometry into elements. Meeting demands To installations, prefab elements. Fabrication design. Elements: Conclusive design.
Auditorium Tasks pertaining to the design /specification of prefab structural elements (concrete)	Spatial programming. User involvement. Setting demands to AV equipment in prefab elements	Revision of drawings to support production. Constructability assessments.	Coordination of room heights. Placing stairs, Placing Apertures. Final wall placements, Meeting flexibility demands	Dimensioning: walls, columns, beams and slabs + secondary const.	Dimensioning, installations.. Dimensioning of floor elements to accomodate to installations	Operator room. Technical drainage system disposition construction input.	Dividing geometry into elements. Meeting demands To installations, prefab elements. Fabrication design. Elements: Conclusive design. Stair-design(subcontract) Constructability.
Ground floor Tasks pertaining to the design /specification of prefab structural elements (concrete)	Setting accesability demands. Ensuring constructability w/ contractor.	Revision of drawings to support production. Constructability assessments.	Conclusive overall geometry. Placing stairs, Placing Apertures. Final wall placements,	Dimensioning: walls, columns, beams and slabs + secondary const.	Dimensioning, installations.. Dimensioning of elements to accomodate to installations	Setting demands to HVAC system design. Technical room /shaft construction input.	Dividing geometry into elements. Meeting demands To installations, prefab elements. Fabrication design. Elements: Conclusive design. Stair-design(subcontract) Constructability.
Floors 1-6 Tasks pertaining to the design /specification of prefab structural elements (concrete)	Setting flexibility demands. Ensuring constructability w/ contractor.	Revision of drawings to support production. Constructability assessments.	Conclusive overall geometry. Placing stairs, Placing Apertures. Final wall placements,	Dimensioning: walls, columns, beams and slabs + secondary const.	Dimensioning, installations.. Dimensioning of elements to accomodate to installations	Setting demands to HVAC system design. Technical room /shaft construction input.	Dividing geometry into elements. Meeting demands To installations, prefab elements. Fabrication design. Elements: Conclusive design.

Table 4, WBS, zones, by the author

5.2.1.3 The work breakdown structure, Core design team

Of the structured interviews conducted in relation to this case, four participant organizations have contributed especially valuable information to the analysis: a representative of the architecture firm, a representative of the engineering firm, the supplier of the prefabricated elements and finally the on-site contractor, represented by both the site management and the assembly crew foreman. These stakeholders have been the main drivers of the design efforts, through the contributions made to the single outcome of the processes, numerically organized below:

A Architect	B On-site D-B contractor	C Struc. Eng.	D Mech. Eng.	E Supplier
A1 Spatial and functional disposition	B1 Revision of drawings to support production	C1 Early dimensioning: Concrete element principles	D1 Dimensioning of installations.	E1 Dividing geometry into elements
A2 Structural core geometry	B2 Construct-ability assessments	C2 Dimensioning concrete slabs, stair wells and ramps	D2 Technical room /shaft disposition	E2 Elements: Conclusive design
A3 Conclusive overall geometry		C3 Dimensioning: walls, columns, beams and slabs + secondary const.	D3 Setting demands to prefab elements to accomodate for installations	E3 Ensuring Construct-ability w/ contractor
A4 Coordination of room heights			D4 Dimensioning of elements to accomodate to installations	E4 Fabrication design
A5 Ramp/stair Design, meeting accessability dem.			D5 Setting demands to electrical conduits in prefab w/ electrical sub	E5 Meeting demands To installations, prefab elements
A6 Placing stairs, Placing apertures				E6 Risk assessments, construct-ability
A7 Conclusive wall placements, meeting flex. dem.				E7 Stair-design(sub-contract) Constructa-bility

Table 5, WBS, core design team, by the author

5.2.1.4 The work breakdown structure, Dependencies

Interdisciplinary stakeholder dependencies, based on the project time schedule (Gantt chart) acquired from the design team, conveyed graphically in trade-specific fields. Fig. 34, an excerpt from a conventional WBS (by the author on case 2), showing task dependencies, but not role dependencies and Fig. 35, the role dependencies not accounted for by the tree structure:

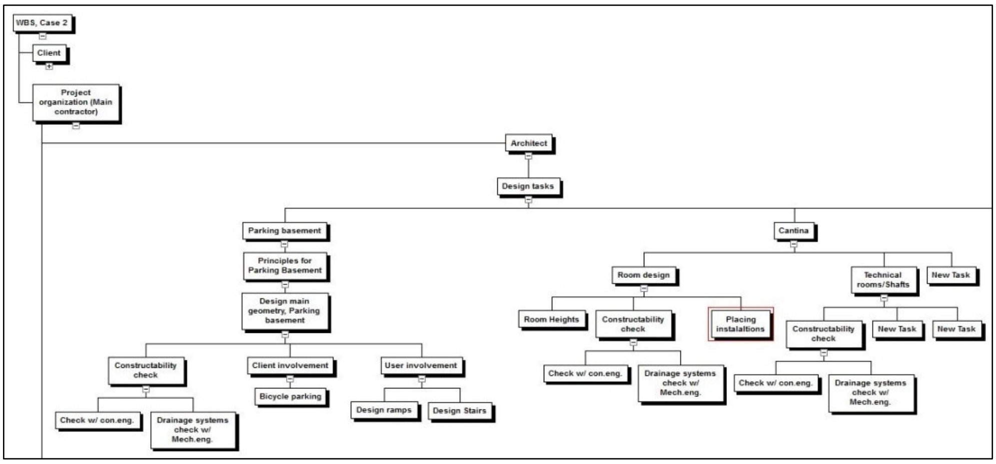


Figure 34, Traditional WBS excerpt, by the author

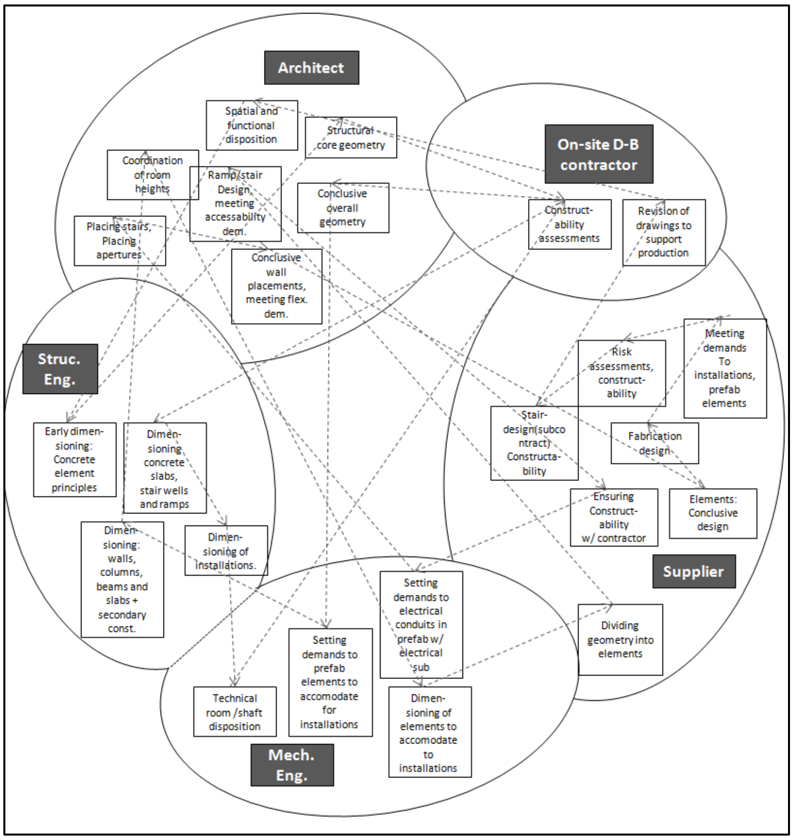


Figure 35, WBS, dependencies, by the author

5.2.1.5 The work breakdown structure, Responsibilities

Looking at dependencies and responsibilities, it is revealed that only one integrated design iteration has taken place (B2,C2,D1,D2) where the rest are transfers being made *between* trades.

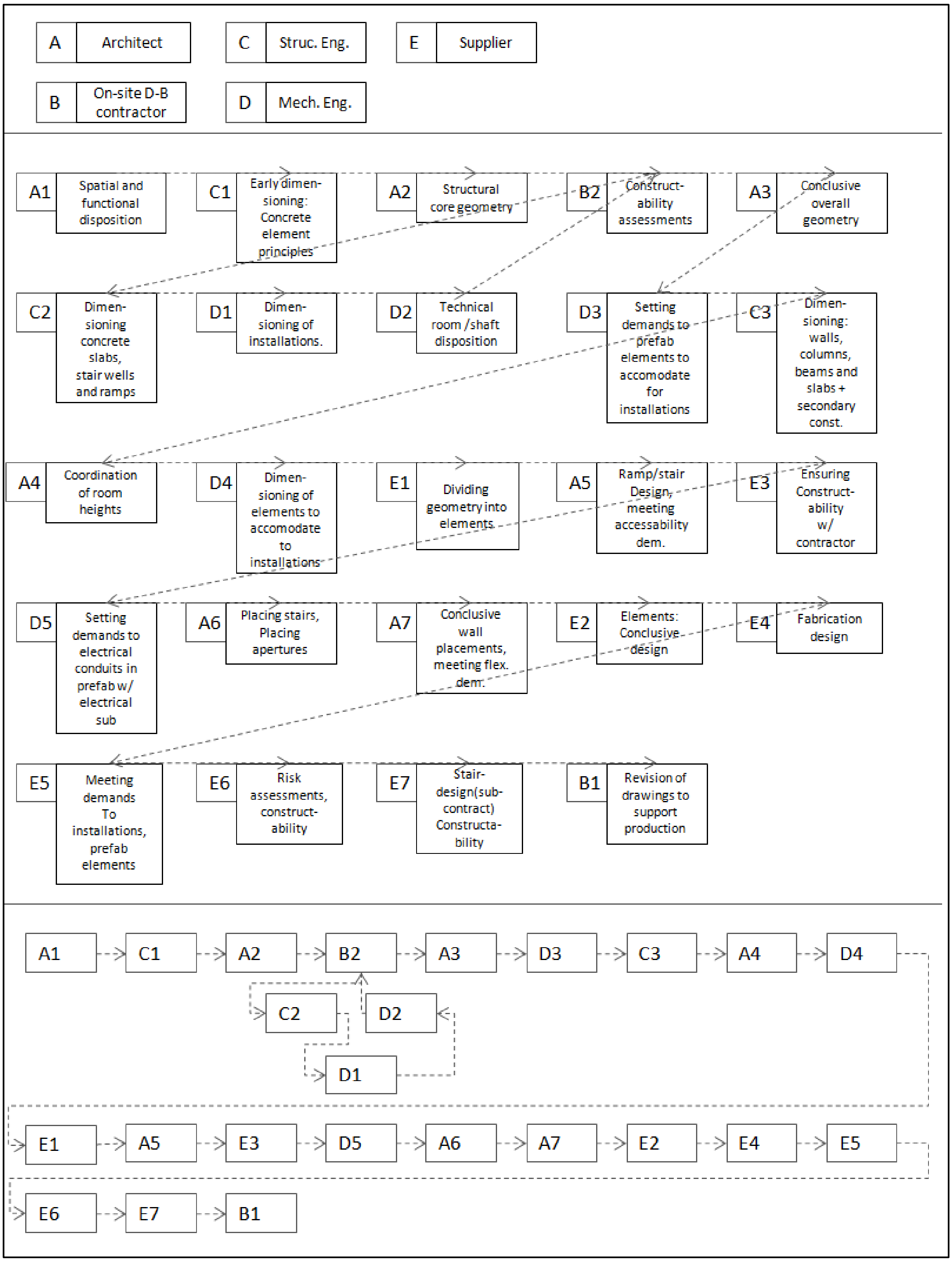
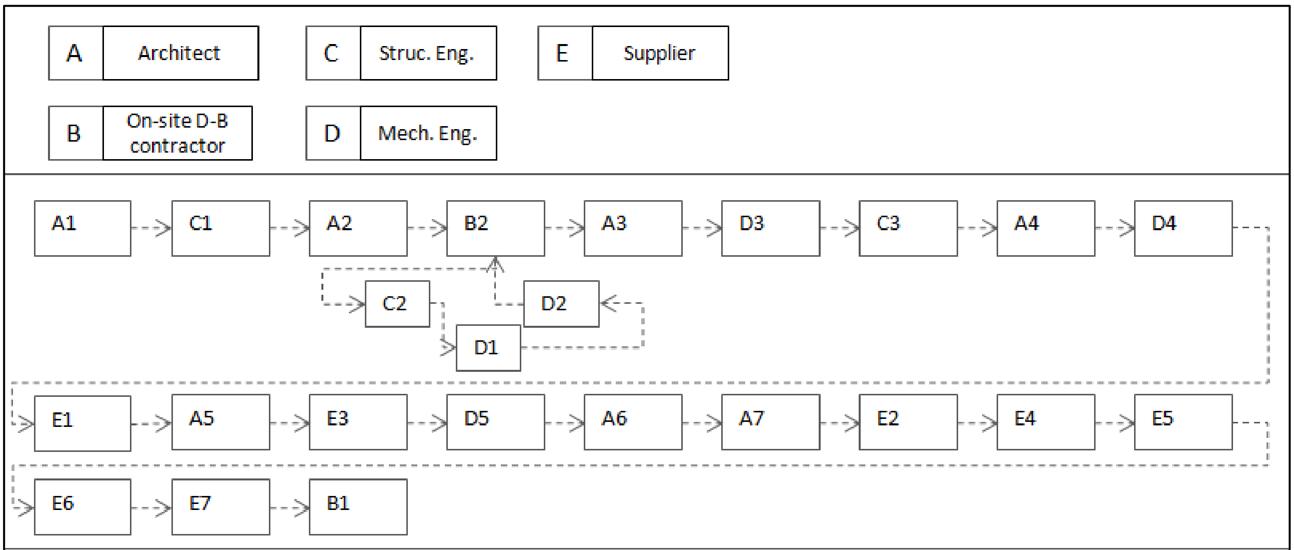
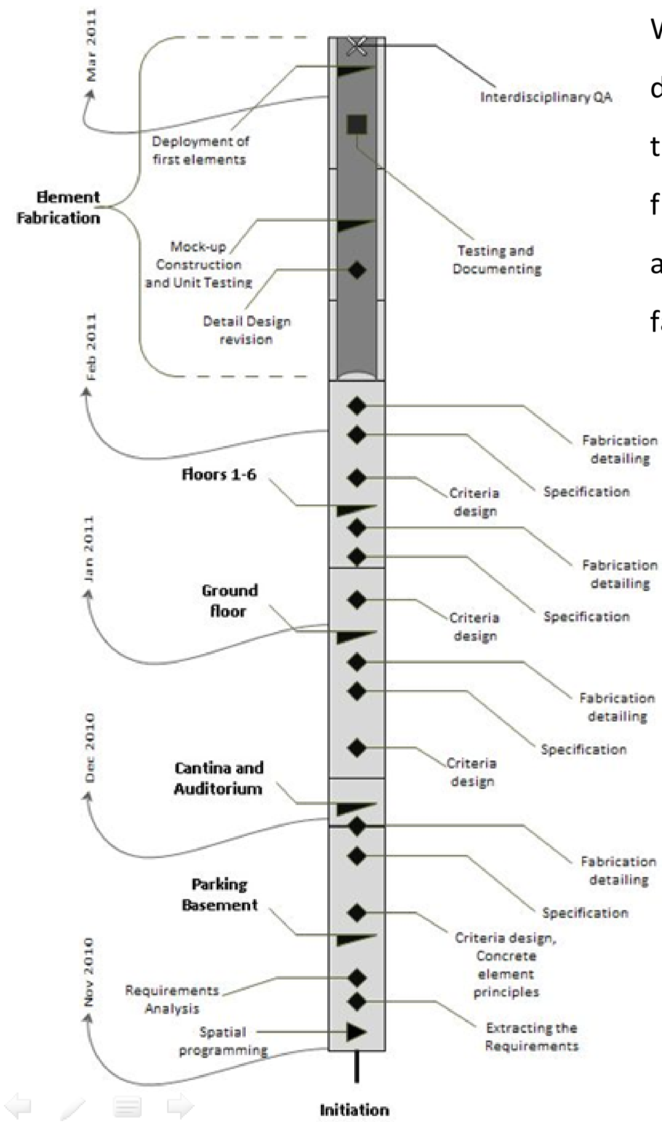


Figure 36, WBS, responsibilities, by the author

5.2.1.6 The work breakdown structure, Scheduling





We can couple the activities and their dependencies to the timeline of the project, to understand the work expected for each functional zone of the finished building, or any other such division, such as product family or contract.

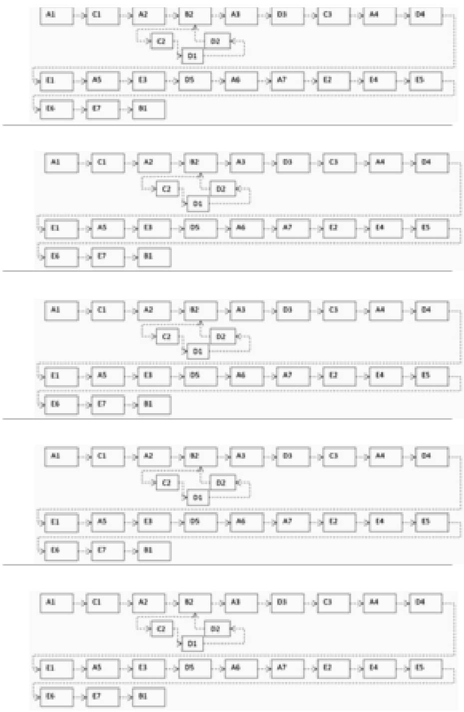


Figure 37, WBS, scheduling, by the author

5.2.1.7 The work breakdown structure, Deductions

In uncovering the mechanisms of a business case, this diagrammatic method can aid in communication and contractual arrangement. If applied to budgeting and/or specifying technological needs, it demonstrates the significance of being able to convey the challenges faced on projects. It remains, however the “negative image” of a project. It can represent all the phenomena which standardization can facilitate, but does not show the full picture of a building project.

The one key metric needed to supplement the techniques shown would be unit-durations for work packages, to determine Lead Time/Down Time of the activities, and the potential precision with which succinct and compressed processes could be planned, if Down Time or another specifically waste-oriented metric could be reduced over the whole of a design management process.

- In analogy: We have the pieces of the puzzle that have standard forms, but in putting those together, the non-standard forms (e.g. innovative work process or flows that are inhibited by external factors) may also be identified. This is a bonus of dynamic planning, because it allows for more and more data enrichment over the course of several projects in a company’s portfolio. This enrichment is retained value for an organization insofar as the data are structured and accessible.

The aspects unaccounted for by methods like these are the phenomena which cannot be planned. Some unforeseen events will persist on building projects that could cause wasteful processes to happen, so the planning exercise demonstrated here also serve to identify the factors not readily planned by project management.

5.2.2 A qualitative account of an interview with an on-site subcontractor

Over the course of this case research, several multidisciplinary coordination meetings were attended and a chance arose to inquire about specific challenges encountered on the build, in relation to the deliveries of prefabricated concrete elements. The approach to analyzing the deliveries (from a quality-assessment standpoint foremost, rather than a supply/logistics standpoint), was to informally address the subcontractor in charge of the concrete elements assembly on site. Moreover, it presented a chance to investigate how the contractors on site are affected by the general circumstances of a specific supply chain. The subcontractor in question offered an informal interview on the subject of information deliveries and, more specifically, how design-problems manifest on building sites, as the final link in the supply chain of construction projects.

The interview is integrated in the report because it is indicative of two seemingly predominant tendencies on construction projects (Berard, 2012):

1. Project (design) material in the form of drawings, models and specifications is not of a sufficient quality to fully support the production and subsequent on-site assembly of building parts,
2. Practitioners generally do not readily embrace change to their usual procedures.

With all due respect, this contractor is a person who, apparently, adheres quite enduringly to tradition in his field of work:

5.2.1.1 Interview summary

Q: *"How do you store information about the work to be carried out?"*

A: *"We got drawings from the consultant team, in paper and DWG format."*

Q: *"2D only?"*

A: *"Yes, 2D only."*

Q: *"No BIM systems have been put to use in the assembly-works on site?"*

A: *"No BIM systems have been put to use."*

Q: *"Having received the drawings, have you identified where your work flows were challenging to sustain, with regard to dependencies on information delivered by other stakeholders?"*

A: *"The project material was a bit delayed at first, but the main issue is that the elements do not fit (the rest of the structure) when they arrive on site. Whether or not this is caused by an insufficient design quality I cannot say. We have to integrate information from 14 different drawings so that our craftsmen can build on the basis of the drawings. It's faster than handling 14 different drawings"*

Q: *"Do you think that contractors should build their own BIMs, e.g. to generate revenue for themselves, through better planning?"*

A: *"There is no time for that."*

Q: *"What if it could alleviate construction problems considerably?"*

A: *"Sure, there are potential gains to be made, but that change will be dependent on the client, he's the one paying for the project, and he's the one allotting time to do it, we don't have the time."*

Q: *"Well, the purpose of addressing you, as the contractor, is to find out if unwanted consequences of an insufficient design do in fact emerge on site."*

A: *"They do, but the fabricator is facing bigger problems. When getting their problems, we just send them right back"*

Q: *"Problems do not occur in your part of the project?"*

A: *"They do, but that's because we receive concrete elements that do not fit together (…) The question is if it's the fabricators fault, or because the design is so flawed that it's practically impossible to build on the basis of it. (…) The fabricator received drawings and produced their elements on the basis of those drawings, but what if the design materials are not sufficient."*

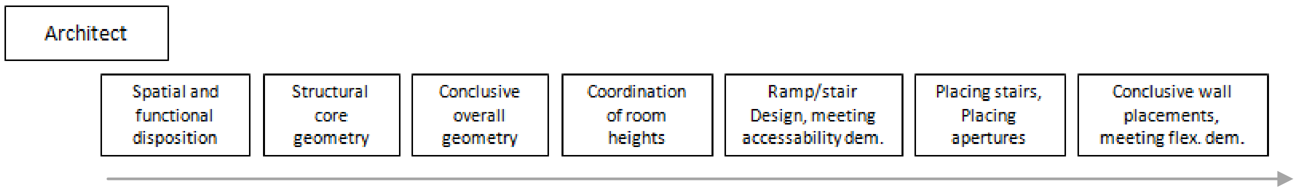
Q: *"Do you know anything about how the material is scrutinized and assured in terms of quality?"*

A: *"I just note that things won't fit together on site."*

5.2.3 Design tasks and related issues

The following key statements of issues (defined here as processes, events or tendencies in which waste has taken place), have been extracted from the interviews. The statements are further illustrated by the tasks of the stakeholders, extracted from the breakdown of the work and shown in diagram form:

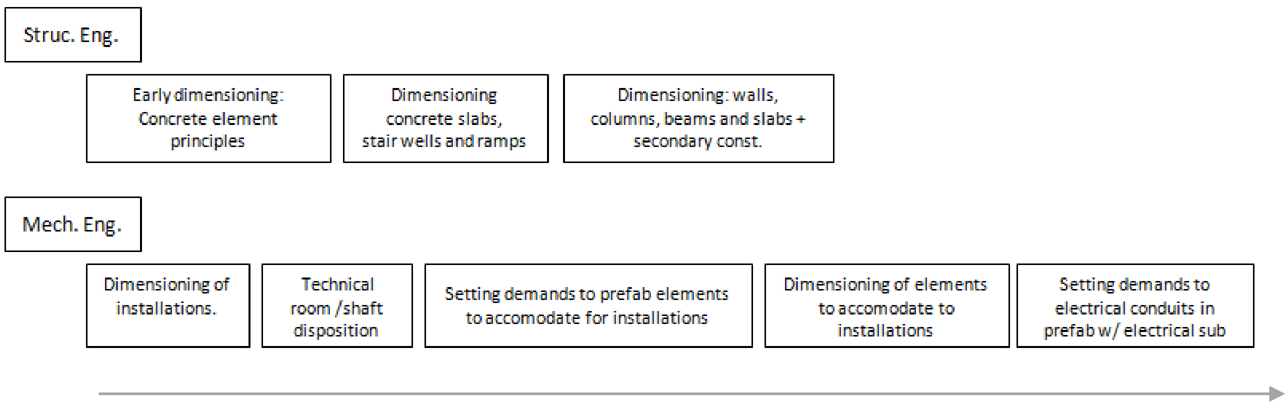
5.2.3.1 Tasks and key statements, Architect



"Discrepancies have occurred with regards to the expectations to the project, because we made a project for the client, but got hired by the contractor"

"The design phase runs for a long time before consultants reach consensus on spaces, structure and installations, and the constructability concerns have taken a back seat to that. We don't know how much detailing is too much"

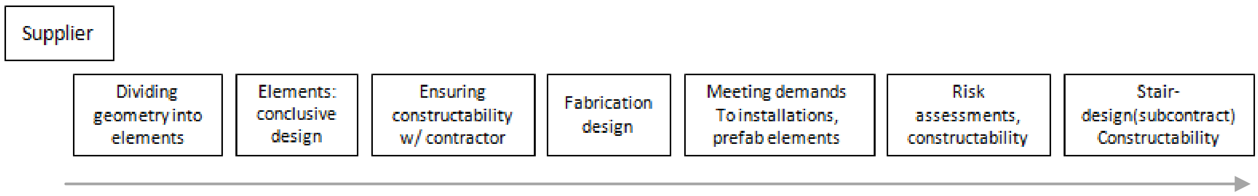
5.2.3.2 Tasks and key statements, Engineer (mechanical/structural)



"Our engineers battled the early involvement of the contractor, because the geometry of the project is unusual and we wanted to have a finished project before the tender process (with quantities), since non-buildable solutions would otherwise be procured, and we would have to pay, as the consultants, if the quantities are not exhaustively taken account of"

"To us this was Design-Build without the involvement, because we didn't have time for the conceptual stages of the project. It went from competition to tender, without assured constructability"

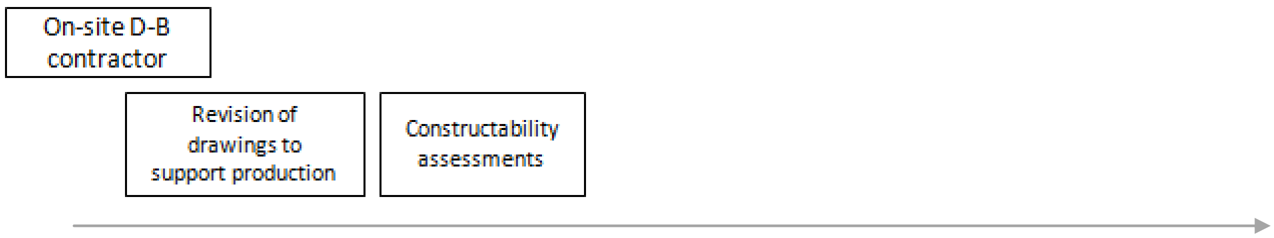
5.2.3.3 Tasks and key statements from the Supplier



"Our client is the contractor -we answer to that organization. We have to deliver the first batches within 8-10 wks. after signing the contract, so any delays or irrelevance in information becomes our problem"

"Receiving information concurrently is fine by us, but this tendency with BIM that the consultants can upload revisions all the time makes it difficult for us. The frequency of revisions must be planned as part of the contract; otherwise our work is oftentimes wasted. (…)The project-organization must collocate on-site, in our opinion, for us to obtain the best possible basis for lean processes."

5.2.3.4 Tasks and key statements from the Contractor



"Problems occur because we receive building parts that do not fit together. The question is if it's the fabricators fault, or because the design is so flawed that it's practically impossible to build on the basis of it. (…)The fabricator received drawings and produced their elements on the basis of those drawings, but that's tough when the design material is not sufficient. (…) I just note that things won't fit together on site".

5.2.3.5 Summary of issues

1. Architectural services (such as design) serve to sell the product to the client, but the contractor expects other things (such as constructability provisions), than a client. Architects have difficulties knowing how much detailing to complete in D-B.
2. Engineers need time to design a project fully (to an agreed level of granularity/ development), before projects are tendered, which it appears was not the case here, because they will become accountable for any mistakes in tendered quantities.
3. Suppliers suffer when asked to deliver on a project with insufficient information. Suppliers are not equipped to handle concurrent revisions/design solutions.
4. Contractors have problems when things do not fit together on site because of a rushed design process.

5.2.4 Conclusions, Case 2

The issues here are 1) expectations to the work contributed by the different stakeholders deviate; 2) time schedules generally do not have sufficient slack to take the “unforeseens” of a process into account; 3) technological possibilities are developing faster than the practitioners’ operating-skills, and 4) unstructured design iterations and quality assurance affect a building site’s efficiency negatively, if this work is not contractually stipulated.

On an industry level, these issues present the optimization barriers which can lead to waste on projects. All the waste can be measured in one currency: time.

5.2.5 Recommendations to collaborating company, Case 2

Time is money, but how do we make time?

On the case in question, the variable quantities of time spent during design work have not been measured or documented, so this following method is shown as one way forward, in the analysis of a building project’s possible optimization.

5.2.5.1 Recommendations to work processes

When addressing an optimization of an organization’s current working methodology, its culture and the atomic work flows in themselves, the selection of a given analysis method must reflect what is needed to develop or elaborate the observed phenomena, to also point in the direction of solutions to the challenges faced. A research method (unless a pilot study is being undertaken) is both a way to indicate the direction that efforts should take to confront the problems at hand, as well as a way to measure the improvement of a given process as dictated by the solution applied. The nature of building projects is such, that early stage problems (c.f. the well-known Macleamy curve) resonate downstream, increasing in effect as time progresses on a project. For this purpose, we need to see how a project flows –rather than optimizing individual silos. Since the academic project at hand attempts to identify where information flows can be improved to facilitate collaboration, the method should point to opportunities of this, and allow for problems to visually (diagrammatically) surface. The focus of this chapter is to show how to document a specific type of systems delivery, on a specific case, to identify the possible problems that may be encountered on-site as a result of inadequately documented design and process planning. The inquiry posits the rhetorical questions: By whom are the object(s)/parcels of information processed, for how long and what is lacking in terms of relevant information at every handover? How are these parameters to be measured and how can the process be graphically/numerically represented, to promote the continuous learning of the stakeholders in question?

5.2.5.2 Value stream Mapping

One such method, developed by the Toyota Company (Rother & Shook, 2003), is Value Stream Mapping, or VSM. The objective of surveying a design approach would be to identify a key metric to measure improvement. In this case reducing “the time between order and cash”, from request to delivery is an obvious way to look at the production line of a design process, since it is the most straightforwardly quantified unit in the work flow. Hence, the pivotal question is: What can we infer from analyzing the information flows that are relevant to the design, fabrication and assembly of one type of systems delivery, through every step of the process, to subsequently apply this analysis to other types of deliveries? Looking at one type of delivery and using that as the infrastructural and behavioral model for the building project as a whole, a representative product or service can teach us about information and interfaces in the design process. This bottom-up approach, as applied to a "semi-generic" system (concrete elements), may be able to shed light on potential optimization efforts throughout the type of contractual arrangement that is applied to the case. The linkage (contractual basis) between suppliers/fabricators, contractors, the client and consultants is the basis upon which the project flow is contingent. Hence: identifying the most advantageous collaboration principle that can be applied to this type of contractual arrangement, is a task most central to design management.

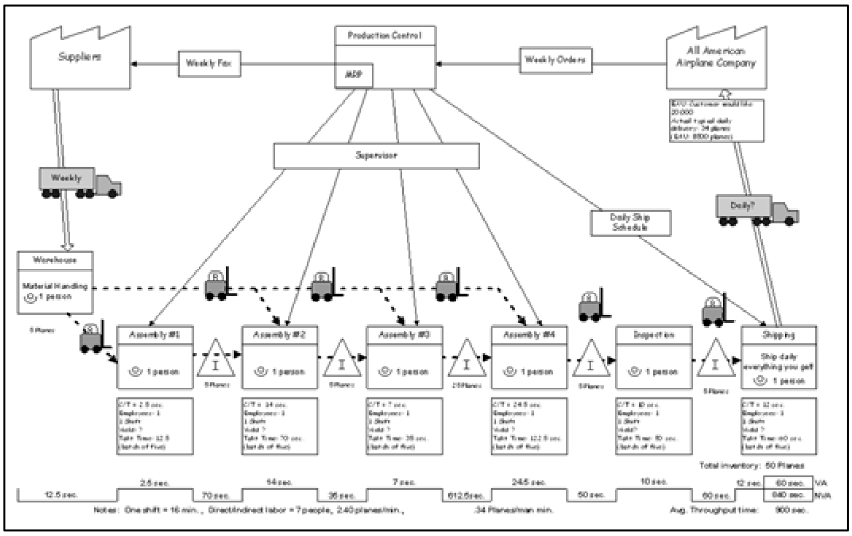


Figure 38, Value Stream Map, source unknown

4.2.5.3 Selection of product family to identify a "model line"

As we have seen, a value stream can be a model for all streams within a similar scope in other product lines and families, especially when dealing with prefab. Value stream mapping provides a pictorial snapshot of information flows from start to finish. Since the general subject of this academic work is how to manage and plan the design process on Design-Build projects, the assignment needs to look at how design efforts may ensure constructability and profitability. This means seeing which parts can be standardized, through the defined activities on the timescale of a design process, learning from systems delivery methods, to apply these to generally occurring processes. This could teach us which parts of a design process are universally applicable to Design-Build projects.

The survey method therefore has two purposes:

1. To uncover the current state on a specific case *(Current state diagram)*
2. To look at optimization potentials in information transactions and work flows *(Future state diagram)*

Subsequently, to ask: "*What can we learn from a perceived 'Ideal state' in relation to design management in general?* This question needs to be asked because the gap between the current state of a value stream and the future state of a value stream is what generates opportunities for improvement (Hajek & Mcmahon, 2012). From the potential areas of improvement, which one(s) will make the biggest difference in meeting recipient requirements, is then assessed.

4.2.5.4 Rationale for recommendation

The approach is chosen for its ability to shed light on several other parameters and types of building element design and installation, because by choosing a relatively low-risk/high impact element as the standard object of analysis, the lessons learned can be used to establish a hypothesis for design management and its impact on a project at large. The initial hypotheses are to be formulated in order to identify problems in the process; progressing backwards from the last point in the supply chain, making assertions "downstream", to identify problems "upstream".

4.2.5.5 Example of Interview template and questions

Delimitation of the product family and survey boundary

- Systems delivery, following the SIPOC (Supply-Input-Process-Output-Customers)

Presumptions about value stream challenges

- Waiting-time, communication problems, rework, lost time, interface problems, high lead time, bottlenecks.

Roles (parties to be interviewed)

- Architect, Engineers, CM, Subcontractors, Suppliers, Client-adviser.

Start point: Client demands (program, budget, etc)

End Point: Logistics on site (Subcontractor's planning)

<u>Initial orientation</u> *"What is the sequence of your work during the design and specification of a systems delivery consisting of pre-fabricated concrete elements?"*

<u>Question 1</u> *"How large are the deliveries being planned at a time and how long does one part of the project take?" (Elaborating question: is the (design of the) delivery lifted to a certain level of detail in one go, or divided into locations/trades?)*

<u>Question 2</u> *"Can the design/specification material be made correctly in the First Time through?"*

Question 3 *"How is information about the delivery stored? (Formats, storage units, etc.)*

Question 4 *"How is the project material assessed for quality and planned?"*

Question 5 *"Which specific BIM/ICT systems have been put to use?"*

Question 6 *"To what extent has your organization been influenced by rework and reentries of data in the project?"*

Question 7 *"To what extent have the demands to the project material been changed in the low between parties, from the original demands made by the client?"*

Question 8 *"Has every change created value for the project?" (how much has been discarded, how many variations/iterations on design solutions have been made to reach the final outcome?)*

Question 9 *"Where has the flow been challenging to sustain, where you have been dependent on someone else to perform your tasks?"*

5.2.5.2 Recommendations to contractual engagement

The contractual relationships on a case of this scale should reflect the need for knowing exactly what fellow participants will contribute. The contract should also specify the amount of slack allowable in activities, to accommodate to unforeseen problems, so that these are taken account for preventively. This points once again to the lack of exhaustive data collection on projects in general, to ensure a learning organization. Moreover, that iterations and quality assurance must be contractually stipulated.

5.2.5.3 Recommendations to application of technologies

The application of technologies should be made to match the skills of the practitioners. On this case, the technologies applied have not been utilized to the full extent of their capacity, because said technologies are unnecessarily advanced, assuredly more so than need be. This is because the actors still practice a decentralized design approach, yet apply tools that are made for collaboration. The operating skills and time schedules on the project do not allow for the management to be trained in current IT-solutions. This means more resources should be allocated to mastering technologies, clearly affirming and warranting the existence of a BIM-department in the company.

5.3 Case Study 3: B+H Architects, Integrated Practice strategies example

B+H, an architecture and planning firm operating out of Vancouver, Canada, have a reputation of advocating a collaborative approach to design, as well as encouraging multidisciplinary input throughout the stages of a project. Their design-procedure is described as “reducing complexity, enhancing quality”. This makes the company a good fit for this third case study on the business model of collaborative design, since this report considers integrated design from the contractor’s perspective on constructability and BIM’s inherent risk management. The contractor’s work is, logically, facilitated by ease of construction, ease of quality control efforts and feasible reductions of build/cycle times in the fabrication/construction phase(s).

The following statement is from the website of B+H and outlines the way design problems are worked with (B+H_Architects, 2012)**:**

“Our Approach to Integrated Design:

Our Integrated Design Process involves eight iterative steps that provide a roadmap for any team, on any project, anywhere. By encouraging structured collaboration with all project participants, we find the optimal solution for every problem. This approach enables us to establish and monitor costs from the initial project feasibility through to the final design phase. If costs go up, we know immediately that we are going in the wrong direction and can adapt and simplify the design accordingly.

Step 1*: Orientation and Massing allows the team to begin to understand the external impacts on the development including the physical aspects (Sun, wind, biomass, water, shading, local eco systems) as well as the contextual impacts (social and economic), and to use this understanding to arrive at an optimal test massing for the development. This massing is modeled to determine its performance.*

Step 2*: Site Design and Water is the point at which the team looks at how the development might maintain, enhance or regenerate the natural eco-systems intrinsic to the site. Solutions for innovative use of water and the creation of green space are developed.*

***Step 3**: Envelope is when the development truly begins to take shape. Roofs, walls, windows and features are defined and modeled in response to the optimal massing and site design developed in the earlier stages. The dynamic effects of the forms are modeled.*

***Step 4**: Lighting and Power, **Step 5**: Ventilation, and **Step 6**: Heating and Cooling, involve the whole team working together to create living breathing buildings. We create beautiful spaces sculpted by natural daylight and fed by fresh air. We use the earth, the mass of the building and hydronic systems to dramatically improve comfort levels while reducing energy use by about 70% on average. We eliminate complex systems and replace them with architecturally integrated components that will last for the life of the building with very little maintenance. Our buildings are healthier and more comfortable and far more energy efficient than average as a result.*

***Step 7**: Materials utilizes our in-house expertise in evaluating substantiation of materials claims regarding toxicity, third party certifications, manufacturing policies and component lists. We favor products possessing a cradle to cradle closed loop life cycle in which the waste stream becomes the production stream. We also incorporate art and cultural artifacts to support and reflect community.*

***Step 8**: Quality Assurance is an integral part of our practice. Every project is carefully peer reviewed and documented to ensure that the knowledge developed during the design phases is transferred through to the construction and operational teams. In this way we preserve the high levels of quality developed during the design phases over the life of the development."*

Figure 39, Projects on which B+H have been involved and design approach, courtesy of B+H, collage by author

5.3.1 B+H's Business Model Strategy

How is an approach to a professional methodology, in this case integrated design, translated into a functioning organizational decree, through which the company can propose projects or submit bids to clients, owners or investors?

The diagram below indicates what kind of hierarchical structure B+H is currently spearheading in their local AEC-industry in British Columbia. It is not conveyed graphically as a chain of command, but as a responsibility matrix. It is said that one potential disadvantage of matrix management is employee experiencing conflicting loyalties, but the conviction is that a suitably managed cooperative environment can counterbalance these disadvantages (johnson, 2012). The matrix shows the following things: a core group of firms representing their respective skills, the roles on a project, advisory functions and responsibilities.

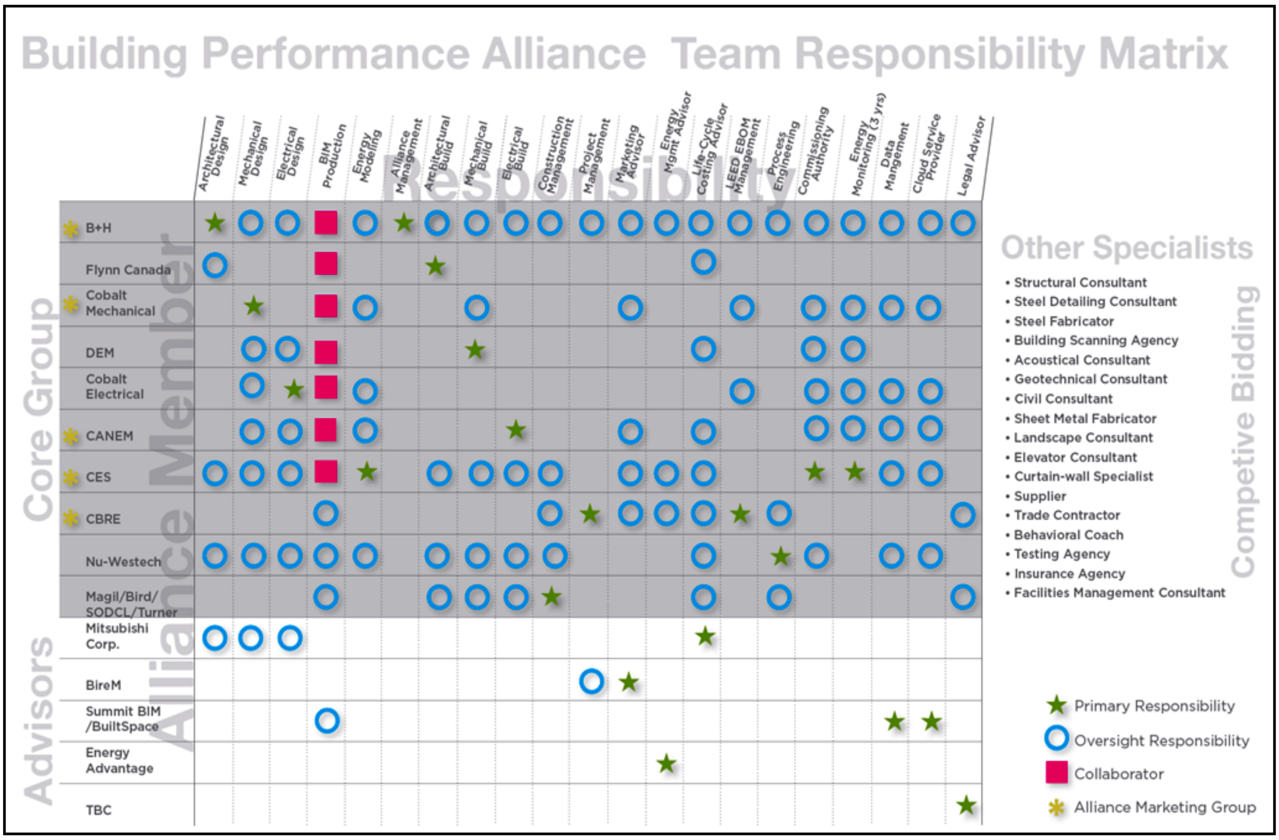


Figure 40, Building Performance Alliance responsibility Matrix, courtesy of B+H

As the matrix suggests, the alliance is focused on offering improved building performance, so the firm's current focal point is the energy-renovation market, called "retrofitting", which has experienced a recent upsurge in business in the AEC industry in Canada, cf. the interview below. What B+H has done is to gather the competencies of a core group and its supplementary advisors, called the Alliance Members, shown as the activities/functions in the top row of the matrix and the roles in the leftmost column, respectively. They are procuring various other specialists and contractors through competitive bidding, for services not included in their own trades. What makes this approach stand out, in terms of the collaboration concepts addressed in this report, is not the matrix organization, the delegation of responsibilities or the alliance aspect of the method; it is in the distinction between primary responsibilities and oversight responsibilities. Essentially, this implies that the roles and responsibilities are more extensive than the work carried out by the individual people/firms and, looking at the diagram, the oversight responsibilities are a good deal more numerous than the primary ones. This might be expected, since one person might be considered a real expert in one or two subjects, but will have knowledge reaching far beyond those core capabilities. If the work of the individual alliance team members (stakeholder-firms) exceeds the billable hours of the services pertaining to their fields of expertise, but the Design-Build contract simultaneously dictates a fixed-price contract, as most do, then people are working more than they are getting paid for (In Denmark the typical Design-Build contract holds its fixed price for at least a year from tendering, depending on the specific contractual bond). However, if the "additional" work implied is a precondition for entering and pursuing the work generated by being part of the alliance team, then it is a very simple mechanism to ensure trans-disciplinary collaboration. *If we hold that a project-collaboration must contractually stipulate the mutual assistance of team members with their tasks, then this will alleviate the tasks carried out by the team members in question, theoretically reducing the lead time of the project in its entirety.* The approach should then be coupled with a design method, such as the one outlined above, a phase model, an actual contract and the supporting technologies needed to pursue assignments warranting this size of an alliance to, theoretically, provide the basis for project collaboration.

5.3.1.1 Communication as contractual obligation

Principally, provided that Design-Build contracts are in fact entered on the basis of shared risks and rewards, then the client will obtain maximum profitability through minimizing those risks. Real-time communication between stakeholders, *as a contractual obligation on the project as a whole*, could potentially keep the material updated on multitudinous aspects of the build, providing a higher degree of constructability. The obligation to support the whole team with knowledge intrinsic to one's own trade –as a responsibility- could theoretically contribute a needed mechanism to the standard agreements of current practice.

5.3.2 An interview with a representative from B+H Architects

Brad Phillips is a senior associate of B+H, an architect AIBC, CP, LEED AP BD+C. From the company's website: *"Brad Phillips has over 20 years of architectural experience conducting construction contract administration services for complex construction projects.* […] *Brad Phillips has experience in all phases of the building development process from the conceptual design stage through to final construction, focusing throughout on maintaining effective and open communication between owners, contractors, consultants and colleagues."*

Aspirations with respect to Integrated Practice

- Can you describe which factors have incentivized your move from traditional collaboration models, to striving for more integration in the delivery of your projects?
  "With regards to incentives, one is (our) experience managing large construction projects using traditional Design-bid-build delivery methods and the second a desire to lead the industry to waste reduction methodologies – extending our "green" (sustainable) reputation"
- Could you please describe an ideal role for your firm in relation to the collaboration principles you are adopting?
  "Our ideals are to bring a varied group together in a common goal –as a way to build trust, and apply it to business cases through developing project specific guidance to collaborators, (by) accommodating access to a single data bank. We are not there yet, however"
- What are your demands to the PM in charge of this process?
  "The demands are to communicate effectively, keeping track of individual shifts by bringing people together to talk. (Another demand is to) remain intent on the project business case and on the quality of the deliverables."

  What are key short and long term plans, with regard to your company's role in your professional context, that is, your local AEC industry?
  "In our context, the first one is growth – as a long term plan to be a centre within our global company as the 'brain trust' leading the way for global collaboratives. Another goal is to

showcase our strength in the construction of quality architecture, in relation to said context"

Potential conflicts / Pitfalls

- What has been the most difficult situation you have so far had to deal with in relation to integrated practice on construction projects?
  "Getting a client to ask for an integrated approach is the current difficulty. We are at present only pursuing IPD for our renovation/retrofit market sector"
- Every project holds risks. A significant part of management is navigating and assessing these risks. What, in your opinion, are the possible pitfalls of integrated practice in the AEC industry?
  "BIM integration is a critical aspect which currently does not offer an interface that can be adopted to consolidate all our data"
- Do you have preventive measures in place, if these pitfalls seem to be imminent?
  "We are working with industry leaders locally to develop an agreeable method that will solve more immediate project objectives and point in the direction of (a) potential long term solution(s)"

Decision Making as a Project Manager/Architect in Integrated Practice

- What has been a difficult decision you have had to make quickly in recent times, concerning the collaboration model you are currently adopting?
  "Adding and dropping members of the Building Performance Alliance based on enthusiasm or the lack thereof"
- In hindsight, was it the right decision?
  "(The) Recent changes seem to have galvanized our 'core group' into action – we are pushing forward on a marketing effort to amplify our message"
- To what extent is your decision making-process informed by the technologies you apply in your work?
  "BIM/VDC is at the core of the Building Performance Alliance methodology. The genesis of the team (participant selection) relates to our role in the BIM deliverables that are products of the work."

Leadership method in collaborative work flows

- How does your firm go about early involvement of key participants, recognized as one of the tenets of integrated design practice?
  "One criterion (for obtaining access to the work) is their eagerness to work in a trust-based environment and to eliminate waste/legal entanglements, currently prevalent on projects. (We want to) use a track-record of innovative approaches to construction and design in our selection of project partners"
- How did you/do you plan to get management and team members on board with this involvement?
  "Team members have come together in a 'business development' initiative spearheaded by B+H and Canem Systems, an electrical contractor. The management at B+H are not 'on-board' but are allowing the collaborative to operate through my time (at the office)"

Accountability / Results through intensified planning

- In your opinion, what is the best way to obtain "design quality management"?
  "By executing a BIM process that starts off with a clear picture of the owner's long term facility management needs/desires and develops with a methodology that has built-in mechanisms for evaluating whether or not those needs/desires are being delivered on"
- How do you analyze/plan to analyze the data exchange needs of the various stakeholders on projects? (This question deals with technical interoperability)
  "We are working in our alliance to identify industry standards currently being developed. We plan test data sources loaded into the BIM/VDC models on the projects, to verify interoperability"
- In your relation to the other consultants and the contractors, do you find your own dispatch control of project material, or the other agent's reception control, is more important?
  "We are not quite there yet, but on (one of) our current modeling-based projects at B+H problems exist in both our dispatch and our reception and we have learned that 'keeping it simple' is important. So, we periodically update the project model(s) and identify revisions to be made"

Role Awareness and goal definition

- How do you make/plan to make the stakeholders aware of their roles on a project? Does your set firm set goals for the other participants?
  "B+H currently acts as a catalyst for goal-setting (in the alliance). We assemble the team and help drive decision making on 'next steps'"
- Do stakeholders know what their contributions should be on integrated projects, and are these contributions different to how they carry out tasks on projects with traditional contractual relationships?
  "That is not yet clearly articulated at the present. More work is needed to identify how we will deal with overlaps and gaps in our team's (overall) level of expertise at various tasks. As it is project-specific (these things) become clearer once a project is started"

Participant selection

- Within your collaborative alliance, cf. the diagram you sent me, how is the competitive bidding carried out? Are some consultants/subcontractors prequalified, or are they selected on their approach or through the lowest bid?
  "We solicit proposals from a list of minimum three companies who amongst the group we identify for those scopes. It is also a selling point to the client, since he/she is then assured that some competitive bidding is also being carried out, since the competition parameter is lowest price on the contract (for those works on the project)"

Skills

- What are the appropriate technologies, for You as a firm, to accommodate to Integrated Practice?
  "(We want) a BIM/VDC authoring tool that we can use to plan (and carry out) the project, that will provide a framework around which the contractual relationship can be described in terms of the interfaces between building elements, functions, work sequences of the trades on site and who enriches the model"

5.3.3 Conclusions, Case 3

Although catering to a retrofit market may not be a desired business model for the collaborating company, the Building Performance Alliance method could be a prediction of how teams will form and collaborate in Denmark in the near future. The viability of the method is yet to be conclusively proven, but the case points to the following preliminary conclusions:

- The client is a central figure in this form of contracting, as the criteria upon which design choices are made and scrutinized should start with his/her organizational and spatial needs. “Alliancing” does not only mean early involvement –it means persistent, continuous involvement through all phases, as needed.
- An established (also by the decree of a client) approach to contracting with a trust-based outlook is needed. The mix of “alliancing” and competitive bidding must be structured to reflect and support the priorities of the client in the assignment of tasks to subcontractors.
- Although retrofit projects will have an owner/client per definition, there is also the aspect of pursuing work implied in this method. An alliance bids and qualifies for a project as an entity, so the method could also be applied to competition or development proposals.

5.3.3.1 Possible adoption of methods in collaborating company

In the Danish Design-Build context, *totalentreprisen,* the closest related form of contracting would be the so-called *rammeudbud,* a contract form defined in the Danish Tender Act, *Tilbudsloven af 18. Maj 2005*. The framework is an official legal document, and therefore not directly comparable to the “alliancing” approach to professional work practice. However, their similarities warrant some juxtaposition: The framework stipulates that the *rammeudbud*-contract is an agreement between one supplier and one customer, which is the main difference. The similarities between the two are numerous: The relative benefits for a client are ensured through financial oversight and by him/her having a proverbial “foot on the accelerator” by controlling the speed of a project according to a budget, made possible by early participant integration. Both forms also entail lower design phase costs, since well-specified design criteria must be imposed by the client. This is certainly the case for retrofit projects, in which the physical constraints of an existing building govern much of the process. The benefits for the contractor include relatively steady revenue throughout projects and known collaboration partners, reducing the risk of information loss.

6. Findings

We can evaluate, on the basis of the literature review and different case studies, what the collaborating company -that is, what the stakeholders observed in their contexts- could do to obtain alignment, operate and create value between the different organizational levels of the company, at the respective hierarchical positions and scales of these organizational levels. To associate the data and find the basis for the strategy formulation of the concluding chapters of this report, we once again turn to the Strategic Triangle (Crossan, Fry, & Killing, 2002), to gather the literature review and the cases in order to appraise. The core of this exercise is to assess potentials of strategic angles, versus the obstacles that are to be overcome, for the following potentials to be realized:

6.1 Optimization potentials through design, planning and constructability

The more informed decision base (through a structured extraction of demands and constraints) and possibilities for obtaining information when relevant, are clear, yet theoretical advantages, as stated in chapter 2.3.3.2. Practically, as established in case 1, the optimization potentials are within reach if trade-interfaces are strictly coordinated to reflect the exact services and responsibilities of the various consultants. Integration thus needs to be as explicitly demanded on a project, as it is implicitly expected. The assigned, collective order that the methods described could provide, advocates a continuous pursuit of structured implementation of the applicable technologies, while monitoring significant design metrics, be it time or cash.

Theoretically, interoperability for trades and departments is the prerequisite basis for relevant quality assurance in the process. Still, many different working methods prevail, for every trade and individual. The methods do not have to be homogenized to a single software suite or a specific type of facility design, but practically the lack of equivalence in the working methods of individuals creates waste in the form of “translation time”: The classification, structure and consistency of transferred information must be aligned for the actors on an individual’s level of the project-organization to obtain the preferred freedom of method. Otherwise, informed, contract-based decision making will not reflect and propel collaboration. As stated, every trade represented should model their contribution *prior to* scrutiny and information sharing, not *for* meetings. The utilization of tools is where implementation starts, but it is sustained through habitual practice. Again, the continuous monitoring of performance and logging of hours spent on distinct activities is a major precondition for the potentials to be realized, and once again this reflects on the learning/improvement capacity of the organization. Exhaustive data collection on the projects, to ensure a learning organization is a primary necessity to support the cause of value creation in Design-Build. Having established that Iterations and quality assurance must be contractually stipulated, cf. case 2 –this, very much so, is also the case for performance measurements. Analyzing time spent, divided into activities and waiting time (up time/down time), may well become a main driver of design phase optimization. If projects tendered are routinely issued as Virtual Buildings/BIM (exact quantities and performance demands), when the tools allowing for integrated design become commonplace; these findings hold that the core competition parameters for Design-Build contractors will become Speed and Quality. Speed: as in reduced cycle times for design iterations to comply with quality requirements, and Quality: as in maintaining said requirements in the face of the “need for speed”. This is included in the findings of this report in that it represents an additional argument for the integration of stakeholders to address time consumption: simpler communication channels mean less time spent.

6.2 Responsibilities in Design-Build management

The following list is from a recipient of the American institute of Architects’ BIM award (Simpson, 2012), the M.A. Mortenson Company –a contractor based in Minneapolis, Minnesota. The award was given for their completion of a successful healthcare project. The company subsequently gathered this bulleted list of responsibilities, as cited below:

6.2.1 Architect (consultant) BIM Responsibilities

- Model proposed building location through massing and site modeling for ideal placement
- Create model
- Manage model through construction documents
- Work with design consultants to incorporate consultant designs into the model

- Incorporate finishes into the model making it possible to create virtual mock-ups of areas
- Share the model with the owner and contractor prior to CDs to allow for constructability review, input from subcontractors and use in the field
- Maintain the model for contract administration.

6.2.2 Contractor BIM Responsibilities

- Review model with Architect and Owner for constructability, pricing and design decisions
- Share the model provided by Architect to our subcontractors for additional detail
- Merge models from subcontractors into working model
- Make model accessible to field personnel on the jobsite
- Hand over as-built model for Facilities Management

In addendum, for the purpose of this report, the following list of client and supplier BIM responsibilities has been written to supplement the findings of chapter 6.1. This is therefore the abridged version of the M.A. Mortenson Company approach.

6.2.3 Client BIM responsibilities

- Persist to be involved throughout the entire process as a “co-designer”
- Aid the project organization in its decision base by making a demand for intermediate communication of solutions at set milestones, for more successful communication
- Assume control of design phase costs, through directing target values
- Make a case for awarding projects to project organizations that collectively agree to eliminate sub-optimization.

6.2.4 Supplier BIM responsibilities

- Create and maintain libraries of 3D models of products
- Adapt to the classification system used on the case, have capacity to overrule own order/production management system with new code
- Engage with core team on designing entire building zones, comprising functional and behavioral performance, as opposed to dividing deliveries into building element categories.

7. Conclusions

Based on the cases, we can infer that in Design-Build management, designers and consultants (architects, engineers, technicians and suppliers) have a broad, decisive role in determining the quality and efficiency of a project. Good design is good business. Time has been wasted on cases 1 and 2, but contradictorily the cases indicate that still more time is needed in design.

On the subject of multi-disciplinary optimization in integrated Design-Build management, two conclusions can be made:

- An integrated design approach starts with posing correct, explicit demands and performance criteria to a building project as it takes shape, in order to minimize the time spent on designing solutions that will comply resolutely with these targets.
- Design work must be fast and ensure constructability, as the real value of a project is realized in its execution. No project was ever commissioned or built if the prospect of value was not apparent.

Simultaneously, the notion of a Project Delivery Team, rather than “stakeholders”, must be pervasive to overcome gaps and/or overlaps. This must be accommodated to in contracts, if the consultants are to fully apply their capacities to the project.

True concurrency can only be achieved in highly collaborative environments, but the two conclusions indicate that the contractor and the client should be driving forces behind this, as the core of the Design-Build team, because the client’s demands, as well as the constructability of the project, both come down to the concept of feasibility.

The AEC industry exists because of its clients and value creation *for* them. The contractor can act on this to produce the value aspired to, but only with relevant, confirmed input from consultants. Meanwhile, the contractor needs to anticipate issues and proactively control production rates. This can be done by putting the client in the proverbial driver’s seat, mandating methods facilitating informed decision making, accommodating to constructability demands by using ICT-tools that allow for collecting and conveying data on all relevant issues, but only in collaboration.

7.1 Answering the problem statement

"How can a contracting firm accomplish its overall project objectives as rewardingly as possible, within Design-Build contract arrangements, on the basis of its design and specification procedures?"

The overall project objectives, elaborated in this report as creating value using effective design/planning, collaboration and constructability principles, can be accomplished by designing to targets and criteria. To do this, design teams must carry forward all design alternatives that cannot yet be eliminated at specific milestones, to ensure that only the fittest solutions possible are authorized, without exceeding the time and budget constraints of the design process.

This makes the consequences of one wrong decision considerably smaller and enforces the capacity of a virtual building and construction model to act as the vehicle for concurrent design improvement, addressing redundancy and waste by aiding in defining interfaces and responsibilities. This goal can be achieved by making an ICT-agreement which (in)forms the contractual basis of a project organization and mandates transparent information sharing, at relevant points.

7.1.1 Argumentation

With the plurality of disciplines represented in D-B, we must be able to quickly create an array of verifiable design alternatives, in exploratory, yet informed ways.

"Why?"

Options created through informed decision-making facilitate refinement of projects and the finding of optimal solutions, to create client-value.

"How?"

Rapid dissemination of solutions as soon as they are arrived at, and testing solutions against target costs and for constructability based on activity-duration data, will facilitate decision making.

"Which would lead to?"

A better understanding of the quality requirements of design partners could reduce cycle times, providing a metric base for choices and ensure continuous improvement of design management practice.

"What is needed?"

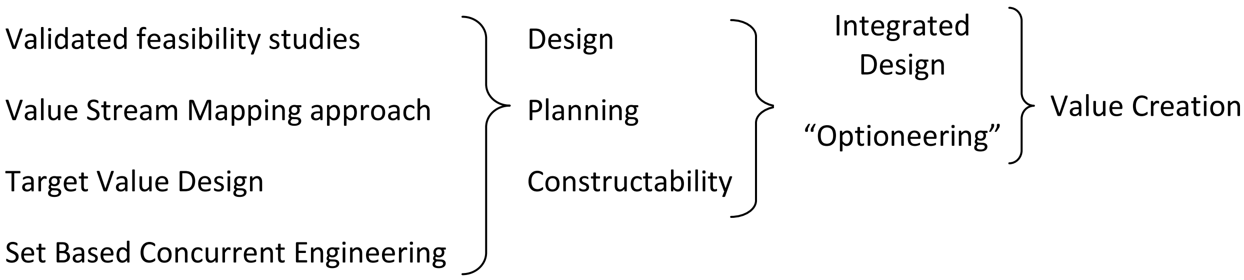
Informative feasibility studies and programming coupled with specified activities, while retaining freedom of method, by applying interoperable ICT-tools to the processes.

From this argumentation, it is apparent that sustaining several design alternatives, abiding by target costs and sharing information are central principles for Design-Build management. However, it also shows that full-scale integrated design/project delivery is a “tall order”, even for large organizations. As we have seen in chapter 3, the industry is moving and current technological implementation is showing growth. Nevertheless, the concepts represented show the status for progressive architects and consultants, who may be well ahead of contractors in the application of technologies to their work. Either the mastery of technologies is confined to specialist or alternatively, more focused Design-Build contracts could be drawn up for specific, delimitated zones or systems, e.g. the structural carcass or another critical part of a project such as HVAC and Facades. This leads to the formulation of a strategy for Design-Build management.

7.2 Strategy formulation for Design-Build

Understanding design tasks means understanding demands, which arguably is fundamental for a design process. Client demands are formulated before the feasibility studies, but are only tested and validated when juxtaposed with actual design solutions. In order to assess whether a design solution is feasible or not, data on similar solutions can form a precedent in the form of regulations, common practice or the verified performance characteristics of the specific solution, providing a key metric by which to compare the solutions with the demands. Assessing whether the process which brings about said solution is feasible or profitable is another, more intricate matter. Here, the precedent collected data values enable both process optimization as well as optimization of solutions produced. The assessment calls for a robust investigation methods that can “progress backwards” through design phases, locating or confirming the recurring impediments to optimization, to make inferences about the project at hand. This once again points to the two aspects of managing complexity, as seen in chapter 3.2: The structural/formal complexity of the designed product is one area in which to optimize, whereas the organizational/institutional complexity is another. A strategy for Design-Build management must attempt to unify the two aspects in one method, while regarding the three strategic angles of the organization.

Companies undertaking projects through the Design-Build model of contracting need to start analyzing information/value streams for future reference, see chapter 5.2.5.2, while satisfying client demands to target costs. This points to one thing: Being able to define the rules that can describe the set of all valid design configurations for a given solution, by giving a score to any given configuration, on the basis of the imposed demands. This in turn implies that a search for the highest numerical score can then select the fittest solution, between several iterations.



Why Set-Based Concurrent engineering (SBCE)? A method both reliant on and supporting VDC/BIM technologies and the production of approved design sets is needed, to fully harness the potentials of currently available technologies. Tool implementation is a prerequisite for value creation.

The SBCE process allows for iteration within time constraints because of the notion of the “set” (Strojniski, 2010).

“A set represents a palette of different solutions to a specific function or problem and can be seen as a family of design proposals. This is opposite to the widely used traditional “Point-based” development methodology, where the selection and approval of one “best” specific product solution is done early when the knowledge of the product is shallow.”

This demonstrates the needed “carrying forward” of design alternatives, advised for in chapter 2.3.2, as the way to obtain the fittest solutions. This is also the connection between Target Value Design and Set Based Concurrent engineering. The three main principles of SBCE are listed below (Strojniski, 2010) with parenthesized comments by the author:

1. Map the design space:

- define feasible regions,

- explore trade-offs by designing multiple alternatives,
- communicate sets of possibilities.

(A wide search for possible solutions.)

2. Integrate by intersection:

- look for intersections of feasible sets,
- impose minimum constraint,
- seek conceptual robustness.

(Eliminating solutions that are not compatible with the main body of solutions.)

3. Establish feasibility before commitment:

- narrow sets gradually while increasing detail,
- stay within sets once committed,
- control by managing uncertainty at process gates.

(A commitment to develop solutions that both match the other sets and fulfill current specifications.)

Thus, SBCE can facilitate the posing of relevant demands to be met and can support the design to target values for the client. Moreover, it can engage the team in gathering design cycle-time data through a value stream approach. The reason for this is that in the execution of concurrent processes, will motivate stakeholders to monitor and register their own contribution because of multi-disciplinary subject matter. Trades documenting the time spent on projects will be fully reimbursed for efforts. This leads to better preconditions for integration, because, as seen in case 2, chapter 5.3.3.2, contributions must be documented to avoid conflicts concerning liability. This outlines a learning organization in continuous improvement.

The integrated project revolves around mutual responsibilities as much as contracts, phase models and handovers. Concurrency does not dictate one phase model, and therefore project specific milestones, on the basis of collected data on the durations of design-phase activities, can govern the development of a building’s design, allowing for solutions to go through the necessary iterations for quality assurance. Hence, a balance must be achieved between fluid collaboration and precisely defined responsibilities.

As demonstrated, there is a correspondence between the prerequisites of Target Value Design and Set Based Concurrent Engineering: Both techniques rely on, and empower, validated feasibility studies (exact client demands) and both techniques advocating sustaining multiple design alternatives as far into the design process as possible. The goals are identical: Every party must engage fully in the process and the design phase(s) must be structured so that a higher degree of performance/cost-feedback can be obtained, and so are the limitations: Fixed targets for cost reductions demand repeatable processes, potentially over the course of several projects. These limitations, however, match up with the Value Stream approach, in that a decision base will take shape through the structured cross-examination of stakeholder/design team activities, over numerous tasks and projects, see chapter 4.2.5.5.

The coupling of the Concurrent Set Based Engineering method and Target Value design through validated feasibility studies requires information about the variables that may be prioritized or deliberately disregarded. Notwithstanding the importance of the cost, time and quality factors, more specific data is needed in an integrated design process.

This list, as proposed by Swedish researchers (Ekholm & Fridquist, 1996), shows a comprehensive catalog of data to take into account, to simulate an operable, built facility (abridged version):

1. Personnel/inhabitant data: numbers, working hours, physical needs, etc.

2. Product and material data: quantities, activity cycles, size, weight, composition, etc.

3. Manufacturing sequence data: data for products and material in a production process; procedures for the work process in administrative or institutional facilities.

4. Furniture, machinery and equipment data: quantities, activity cycles, size, weight, required installations, etc.

5. Construction (and process) support: mechanical and electrical systems, HVAC-systems, plumbing, lighting, maintenance, waste disposal, pollution control, fire control, etc.

6. Personnel support: food services, break and recreational facilities, parking, first aid, etc.

7. Activity areas: Activity areas are organizational units based on functional or product/process based grouping of activities. All project data on flow, communications, space, equipment, personnel, etc. are collected and reported by activity area.

8. Material flow: Data on material flow between activity areas; by estimates; by work sampling or other formal survey; by extraction from production, control reports; etc.

9. Communications: Data on communication based on surveys which display both the overall communication pattern and the aggregate relationships between inhabitants/workers.

10. Activity relationships: Communications and flow are the chief bases of relationships between people and departments; other issues are shared supervision, shared equipment, shared records, shared utilities, etc.

Of these ten types of data, only number 4 and 5 deal with the physical building, whereas the rest are data on the use of a building, indicating that a focus on collecting data on the construction process alone may be inadequate to see a full picture of the projected facility.

7.3 Strategy for Design-Build

This strategy works with an idea of sectioning the multidisciplinary optimization approach into sub-projects/zones. We have seen that the knowledge base of each trade specialization could be harnessed more profitably by working collectively in sets, than if assigned to finding and refining one solution at a time. Design-Build projects need to have design teams working on specific functional or temporal-spatial zones of the building, encompassing all the trades contributing to the solutions within that zone.

The Integrated Project Delivery method, as seen in chapter 2.2.1, is a powerful way to mobilize a project organization, but some sub-projects/zones will be more critical than others. Primary design services, or building parts, can be organized in sets of stronger and weaker interdependencies. For instance, the structural carcass, the HVAC system or the façade system can all be considered sub-projects within the project as a whole, but these sub-projects impact every other aspect of the designed building, c.f. chapter 2.2.1.5, 2.3.2 and 3.2. Below are illustrations of the concept.

7.3.1 Semi-autonomous integration framework

A fully integrated collaborative environment starts with relational processes, but is dependent on technologies. The “semi-autonomous integration” concept is an attempt to coordinate these two factors. The concept is made up of mini IPDs where applicable/critical and normal competitive bidding where applicable/critical. The client and the contractor should define the zones/sub-projects in common. The design team will be under one multi-party contract, in the frame of a consortium or similar, in which some systems call for being more integrally procured than others.

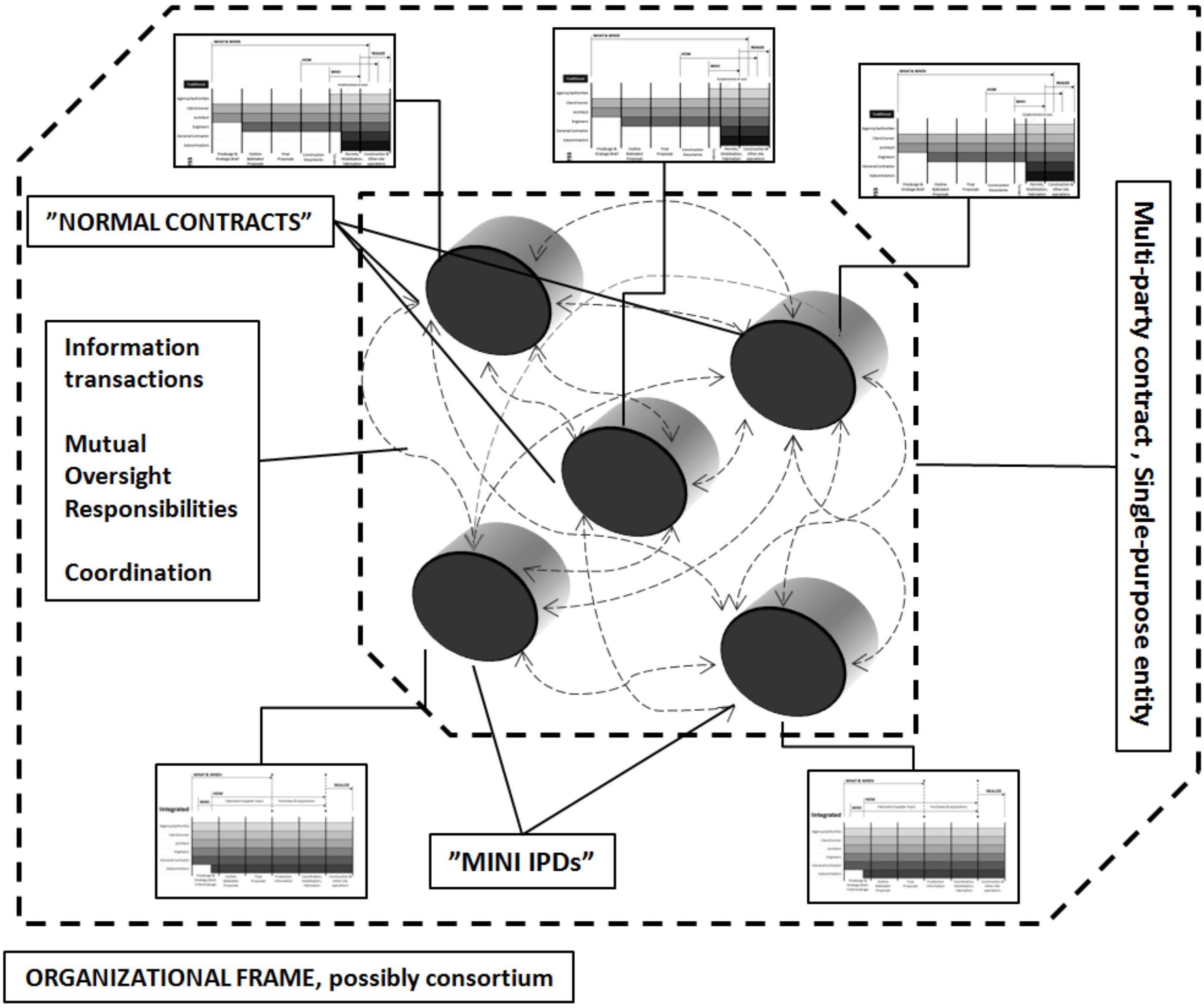


Figure 41, Mini-IPDs, by the author

7.3.2 Suggested work flow and related issues

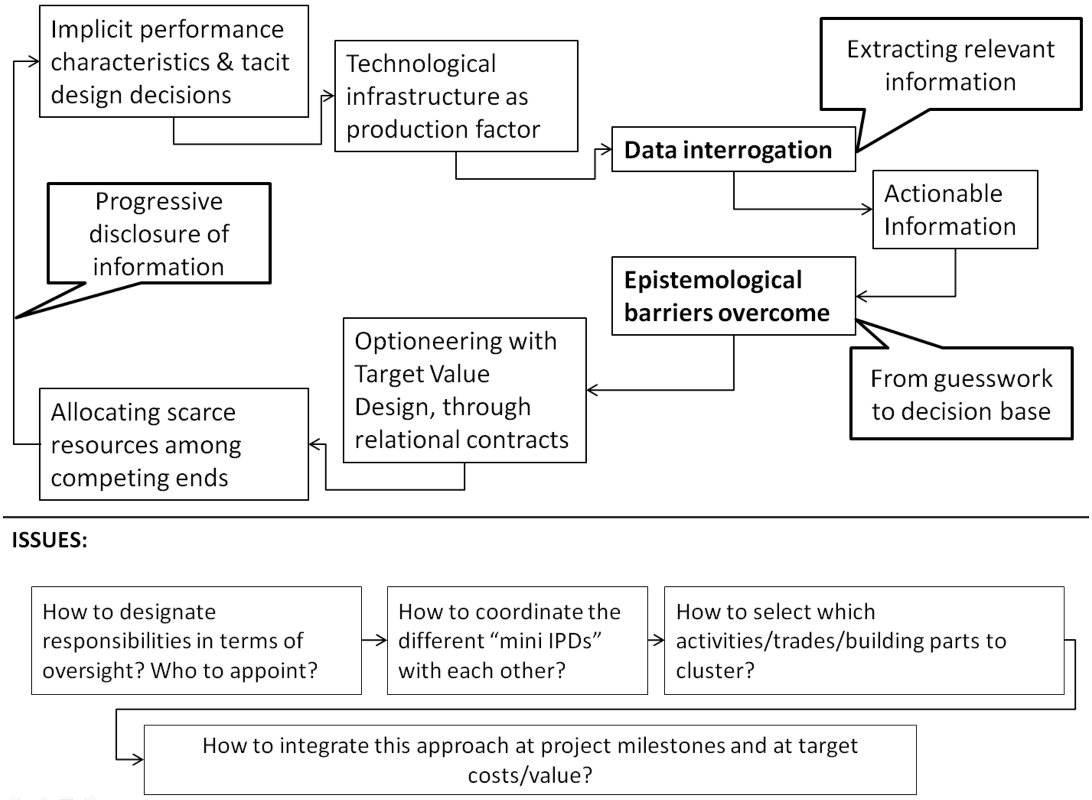


Figure 42, Suggested work flow of framework and issues, by the author

8. Discussion and reflection

A retrospective view of academic challenges and lessons, in first person:

8.1 Reflection on future/related work

The possibilities for conducting a quantification of different professionals' outlook towards integrated practice, for instance in questionnaire form, could be a next step for studies of these and related phenomena, with regards to this procurement model. Implementation comes next.

8.2 Reflection on collaborating company

Again, I want to convey my gratitude to the collaborating company for letting me do my project with their BIM-department. Any related work should pick up where this research ends by documenting the unit times of the activities in a design process, to begin optimizing the different durations in connection to each other. I implore the company to begin a registry of their own and this study is a clear encouragement to fellow students/researchers to do the same.

9. References/Bibliography

Achten, H. (2007). *Design methods and design theory for architectural design management.* TU Delft.

Ashcraft, H., & Shelden, D. (2011). *BIM Implementation Strategies.* Gehry Technologies.

Ashworth, C. (2011). The Adoption of BIM.

B+H_Architects. (2012). *Our Approach, B+H.* Retrieved from B+H Integrated Design Principles: http://www.bharchitects.com/en/B+H/our_approach

Ballard, G. (2012). *Target Value Design* .

Ballard, G. (1999). *Can pull techniques be used in design management?*

Bedrick, J. (2008). Organizing the development of a Builiding Information Model. AIA.

Bejder, E., & Olsen, W. (2011). *Anlægsteknik 2, Styring af byggeprocessen.* Anlægsteknikforeningen.

Berard, O. (2012). *Building Information modeling for managing Design and Construction -Assessing design Information Quality.* Danmarks tekniske universitet, Dept. of Civil Engineering.

Bertelsen, S. (2012). Den Evige Trekant. *Trimmede Tanker* . Foreningen Lean Construction Danmark.

Beyer, H., & Holtzblatt, K. (1997). *Contextual design.*

Birch, Svidt, & Christiansson. (2009). Prototype development of of an ICt system to support Construction Management based on virtual Models and RFID. *Journal of Information technology in Construction* (19).

Bogh, K. (2009). *Byggeriets planlægning og styring*. Hentet fra http://personale.vitusbering.dk/kcb/linkside/BPSlink.htm

Boligministeriet. (1993). Almindelige Betingelser for Totalentrepriser. *ABT93* . København: Boligministeriet.

Box, H. (2007). *Think like an architect.* University of Texas Press.

Broyles, L. (2011). Design/Build vs. architecture firms. *Construction Digital* (6).

Bushell, D. (2012). *Nestable*. Retrieved from dbushell.github.com: http://dbushell.github.com/Nestable/

Cadle, J., & Yeates, D. (2008). *Project Management for information Systems, 5th edition.* Pearson Education Limited.

Cham, K., & Johnson, J. (2007). Complexity Theory: A Science of Complex Systems? *M/C Journal 10.3* .

Chan, A. (2001). *Framework for measuring success of construction projects.* Queensland Institute of Technology.

Christoffersen, Ø. (2012). Demanding clients setting standards in the global market. Statsbygg.

Cinark. (2006). *Cinark sætter fokus på brugerinddragelse.* København: Lene Dammand.

CITA, C. f. (2012). *Confluence -establishing data flow from design to site*. Retrieved from karch.dk: http://www.karch.dk/dk/Menu/Om+skolen/Arrangementer/BIM+symposiumr%C3%A6kke%3A+Confluence+-+Establishing+data+flow+from+Design+to+Site

Cousins, B. (2011). Design Management - Lean Process Management. *AIA TAP faster forward* . American Institute of Architects.

Cousins, B. (2011). Lean Process Management. American Institute of Architects.

CRMByggefakta. (2012). *Tal og tendenser.* Magasinet Ejendom.

Crossan, M., Fry, J., & Killing, P. (2002). *Strategic Analysis and Action.* Pearson Education Canada.

Crotty, R. (2011). *The impact of building information modeling, transforming construction.* Routledge.

DanmarksStatistik. (2012). StatistikBanken.

DanskeARK&FRI. (2012). Ydelsesbeskrivelser for byggeri og planlægning 2012. *Ydelsesbeskrivelser for byggeri og planlægning 2012* . DanskeARK&FRI.

Denton, H. (1997). Multi-disciplinary team based proect work: Planning factors. *Design Studies* .

DetDigitaleByggeri. (2011). *http://www.detdigitalebyggeri.dk/tech-article/informationsniveauer*. Retrieved from http://www.detdigitalebyggeri.dk: http://www.detdigitalebyggeri.dk/tech-article/informationsniveauer

Deutsch, R. (2011). *BIM and Integrated design.* The American Institute of architects.

Dorst, K. (2010). *The nature of design thinking.* Eindhoven University of technology.

Eastman, C., & et_al. (2012). *BIM handbook : a guide to building information modeling for owners, managers, designers.* John Wiley & Sons.

Edwards, G., & McDonough, M. (2011). *Bright Hub.* Retrieved from www.brighthub.com: http://www.brighthubpm.com/project-planning/68427-successful-project-milestone-planning/

Ekholm, A., & Fridquist, S. (1996). *Modeling of user organizations, buildings and spaces for the design process.*

Furhmann, O., & Gotsman, C. (2005). *On the Algorithmic Design of Architectural Configurations.* Technion, israel Institute of technology.

GehryTechnologies. (2012). *GehryTechnologies*. Retrieved from GTeam: http://www.gehrytechnologies.com/gteam

Hajek, J., & Mcmahon, T. (2012). Lean leadership for supervisers.

Haynes, D. (2012). *AECBytes.* Retrieved from Analyses, research and reviews of AEC Technology: http://www.aecbytes.com/viewpoint/2012/issue_63.html

Howell, G. (2000). *The Last Planner system of production control.* University of Birmingham.

Howell; Macomber; Barbaeiro. (2007). *Target-Value Design: Nine foundational and six advanced practices for delivering surprising client value.* Retrieved from http://www.leanyc.org/Target_Value_Design__LPC_.pdf

Huthwaite, B. (2012). Why is Lean Design Important?

ingels, B. (2010). *BIG profile.* Bjarke Ingels Group.

ISO. (2010). *ISO 29481-1:2010.* http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=45501.

Jaeger, R., & Halliday, T. (1998). *On confirmatory versus exploratory research.* University of Southwestern Louisiana.

johnson, R. (2012). *Advatages and disadvantages of matrix organizational structures in business organizations.* Retrieved from Smallbusiness: http://smallbusiness.chron.com/advantages-disadvantages-matrix-organizational-structures-business-organizations-26350.html

Jørgensen, B. (2007). *Projektering til Target Cost.* Retrieved from Documents and resources for small businesses & professionals: http://www.docstoc.com/docs/52079036/Projektering-til-target-cost

KarlsruheInstituteofTechnology. (2010). *Karlsruhe Institute of technology*. Retrieved from Institute for technology and Management in Construction: http://www.tmb.kit.edu/english/Forschung_1623.php

Katzenbach, J., & Smith, D. (2003). *The Wisdom of Teams: Creating the High-Performance Organization.* HarperBusiness.

Kent, D., & Becerik-Gerber, B. (2010). Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery. *Journal of Construction Engineering and Management* .

Koskela, L., & Howell, G. (2002). *The underlying theory of Project management is obsolete.* Project Maagement Institute.

Lahdenperä, P. (2012). Making sense of the multi-party contractual arrangements of PP, PA and IPD. *Construction management and economics* .

Laine, L. (2012). BIM in Skanska.

Laiserin, J. (2008). *Form-making vs. Form-finding*. Retrieved from dcc-form: http://www.cc.gatech.edu/~ellendo/dcc-form.htm

Laitinen, J. (2012). Development of BIM in Finland. Århus.

Laseau, P. (1980). *Graphic thinking for architects and designers.* Van Nostrand Reinhold co.

LCI. (2007). *Target Value design.* Retrieved from leanconstruction.org: http://www.leanconstruction.org/chapterpdf/chicago/2012-06-14-lci-chicago-tvd-lpc.pdf

Leontiadis, C. (2002). *A Study on the problems encounterd when using design/Build in Construction.* University of Hartford.

Lindhard, S. (2011). *Anlægsteknik og Projektledelse med Lean.* Aalborg Universitet.

Lucas, C. (2006). *Quantifying Complexity Theory*. Retrieved from The Complexity & Artificial Life Research Concept: http://www.calresco.org/lucas/quantify.htm

McGrath, R. (2003). *XML and Scientific File Formats.* University of Illinois, National center for Supercomputing applications.

McMullan. (2012). *mcmullan.net.* Retrieved from www.mcmullan.net: http://www.mcmullan.net/

Mengiste, S. (2012). *Structuration Theory & The Structurational Model of Technology.* AAU.

Morgenson, & Harvey. (2002). *The New York Times Dictionary of Money and Investing.* NYTIMES.

MTHøjgaard. (2011). *Årsrapport 2011.* MTHøjgaard.

Mueller, V. (2011). Developing open systems and methods for collaborative modeling. *Technologies in Architectural Practice.* American Institute of Architects.

NIBS_WBDG. (2012). *National Institute of Building Sciences.* Retrieved from The Whole Building design Guide: http://www.wbdg.org/design/engage_process.php

NIST. (2004). *National Institute of Standards*. (NIST) Retrieved from www.nist.gov: www.nist.gov

Nolte, T. (2012). Concurrent Design Practice. Gehry Technologies Europe.

Nonaka, I., & Konno, N. (1998). *The concept of Bá: Building foundation for knowledge creation.*

Olsen, W. (2011). Anlægsteknik . *Plancher, første kursusgang* . AAU.

Olsen, W. (2011). Anlægsteknik kursus. *Kursusgang 1* . Aalborg Universitet.

Osborn, A. (1957). *Applied Imagination: Principles and procedures of creative problem solving.* Scribner.

Partridge, A. (2008). Integrated Project Delivery. Royal Architectural Institute of Canada.

Picon, A. (2011). Digital crafting: Emergent reality or regressive utopia? *The digital crafting symposium.* center for IT and Architecture.

Pouchard, L., & Cutting-Decelle, A.-f. (2007). *Ontologies and standards-based approaches to interoperability for Concurrent Engineering.* Taylor & Francis.

Preece, & Rogers. (2002). *Interaction Design.* J. Wiley & Sons.

Pugh, S. (1990). *The Design funnel.*

Reed, D. (2011). True value engineering. *VDC Rambøll.* DPR Construction.

Rother, M., & Shook, J. (2003). *learning to see. Value stream mapping to create value and eliminate muda.* Lean Enterprise Institute.

Sacks, R., Koskela, L., Dave, B., & Owen, R. (2010). Interaction of Lean and Building Information Modeling in Construction. *Journal of construction and engineering management* .

Sadeh, A., Dvir, D., & Shenhar, A. (2000). *The role of contract type in the success of R&D defence projects under increasing uncertainty.* Project management journal.

Schwabe, D. (2012). *Theory of creating value.* Retrieved from nerdbusiness.com: http://nerdbusiness.com/blog/my-theory-creating-value

ServaSoftware. (2012). *batchable.html*. Retrieved from Interface batchable: http://www.servasoftware.com/documentation/twaver_javadoc/twaver/Batchable.html

Simpson, K. (2012). *central Washington Hospital Expansion project.* American institute of Architects.

Skanska. (2012). *Our core values*. Retrieved from The five zeros: http://www.usa.skanska.com/about-skanska/our-core-values/the-5-zeros/

Smith, D. (2008). *Whole Building Deisgn Guide*. Retrieved from WBDG a program of the national institute of building sciences: wbdg.org

Sowards, D. (2004). *yourqss.com.* Retrieved from Quality support services: http://yourqss.com/node/34

Strojniski, V. (2010). *Practical Apllications of Set-Based Concurrent Engineering in Industry.* Journl of mechanical Engineering.

Svidt, K. (2010). ICT and Knowledge Representations. Aalborg University.

Thein, V. (2011). *Industry Foundation Classes (IFC),BIM interoperability through a vendor-independent file format.* Bentley.

Titus, S., & Bröchner, J. (2005). Managing information flow in construction supply chains. *Construction Innovation: Information, Process, Management* .

VærdiskabendeByggeproces. (2012). *Projektoptimering.* Værdiskabende Byggeproces.

Vico. (2012). *http://www.vicosoftware.com/model-progression-specification/tabid/85227/Default.aspx*. Retrieved from http://www.vicosoftware.com/: http://www.vicosoftware.com/model-progression-specification/tabid/85227/Default.aspx

Waddell, B. (2011). *www.evolvingexcellence.com.* Retrieved from Thoughts on Lean Enterprise leadership: http://www.evolvingexcellence.com/blog/2011/07/why-lean-is-not-a-cost-reduction-strategy.html

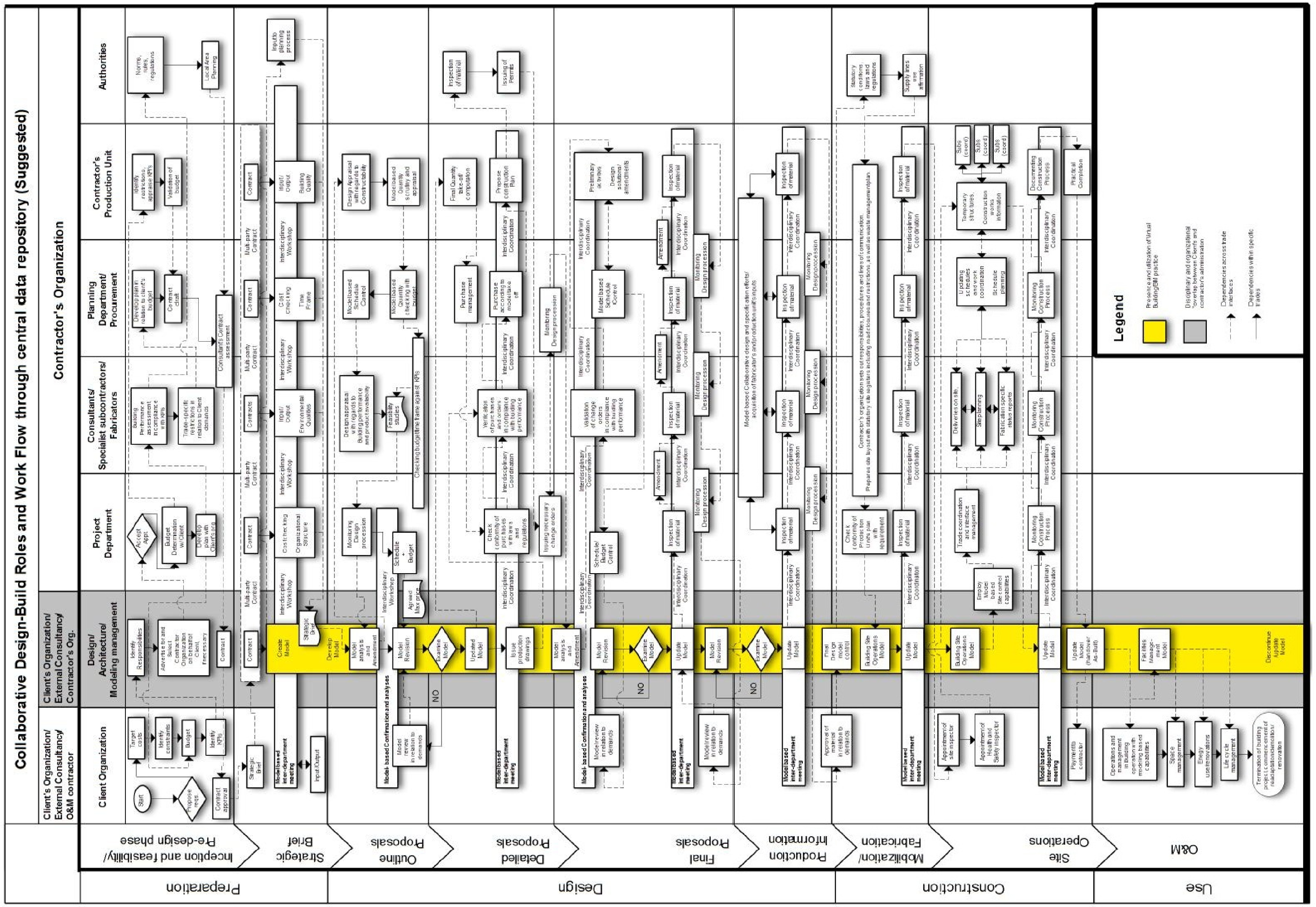
Wiggins, g. (1989). *Methodology in Architectural Design.* Massachusetts Institute of Technology.

Zimmerman, A. (2010). *canadian mortgage and housing corporation.* Retrieved from cmch-schl.gc.ca: http://www.cmhc-schl.gc.ca/en/inpr/bude/himu/coedar/upload/Integrated_Design_GuideENG.pdf

10. Images

10.1 Tables

11. Annex



Collaborative Design-Build Roles and Work Flow through central data repository (Suggested)
Contractor's Organization
Client Organization
Design/ Architecture/ Modeling management
Project Department
Consultants/ Specialist subcontractors/ Fabricators
Planning Department/ Procurement
Contractor's Production Unit
Authorities
Legend
Preparation
Design
Construction
Use