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## SAFETY DESIGN INTEGRATED IN THE BUILDING DELIVERY SYSTEM

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### ABSTRACT

In construction, it is important to view safety and health as an integrated part of the way that “designers” are working. The designers covers architects, constructors, engineers and others who carry out their consulting services in the design phase of a construction project. The philosophy is simple, if the demands for safety and health are incorporated early on in the solving of a building assignment, then it becomes much easier to organise the executing phase in a responsible manner safety-wise. But, the problem is that very few of the designers have knowledge or experience of how to do so.

The purpose of this article is to demonstrate how safety and health can be integrated in the design phases integrated in the management delivery systems within construction,

The method for the research was to go through the building delivery system step by step and create a normative description of what, when and how to fully integrate safety in each part of the process.

The result is a concept and guideline including control forms for how to integrate safety design in the Building Delivery System plus what to do and when. The concept has been tested in an educational context.

The practical value of the concept depends, nevertheless, on how you manage and organise the detailed design process. In the end, prioritization, motivation and leadership are of vital importance to the construction process and to how good the safety at the site will be for the craftsmen. The developed concept has to be seen as a valuable and practical tool for obtaining the safe site.

**Keywords:** Lean construction, safety and health, design, buildability.

### 1. INTRODUCTION

It is a well-known fact, both nationally and internationally, that the construction industry is a generally risky business (Work and Health in the EU – A Statistical Portrait 1994-2002, Eurostat; Jørgensen, 2008; Gambatese et al, 2008; Smallwood, 1996; Toole et al, 2006; Behm, 2005). The EU has documented that 1/3 of the comparatively many and serious occupational accidents in the construction sector are a result of flaws and defects in the client’s and the consultant’s detailed design, and 1/3 are a result of flaws and defects in the contractor’s planning (The European Foundation for the Improvement of living and Working Conditions, 1991). A series of research projects also demonstrates that the design forms the basis for safety (Gambatese et al, 2008; Smallwood, 1996; Toole et al, 2006; Behm, 2005). The necessity of incorporating the question of safety into the construction process early on has been a recurring theme throughout the last 20 years.

The ideal situation for the safety of the construction workers is to make this an important parameter for planners and designers in the conceptual and preliminary design phases (Szymberski, 1997; Gambatese et al, 2008). This served as the basis for the EU directive of 92 (Council Directive 92/57/EEC of 24 June 1992) concerning minimum demands for safety and health at temporary construction sites, where the role of the building planner, be it the client as well as the architect and consultants, is emphasized as having the responsibility for drawing up a plan for safety and health during execution of the construction project.

Safety design has been a topic that has been dealt with in the product and production fields over many years since Perrow’s pioneer work (Perrow,1983) especially with a focus on engineering design and the neglect of

human factors. Ergonomic problems in particular have been studied in association with the development of products and processes in the industry (Broberg, 2007) and on areas such as railways, where Lamonde has focused on activity oriented ergonomic transport (Lamonde, 1996). In this context, safety design does not simply focus on technical solutions, but also on activities, processes, involvement of users, etc. (Fadier & De la Garza, 2006). However, it does not look as though this comprehensive knowledge has found its way to designers of building projects (Frijters & Swuste, 2008).

The nature of the construction project presents a barrier in itself when implementing both safety and quality into the building process (Loushine et al, 2006). The construction industry is a project-based industry that exists in a dynamic and ever changing environment (Lindgard and Rowlinson, 2005). The tenderers' focus on price instead of e.g. safety often causes contractors to leave out the costs for safety and health from their bids (Brooks, 1993). Even though safety and health are required in the pricing, they are not incorporated as well as they should be into the preliminary work on the construction project (Oluwoye and MacLennan, 1994). These circumstances strongly indicate how the work environment during the execution phase depends on prior planning and on considerations for safety and health in the planning phase. They also indicate a need for clarifying the requirement of incorporating the demands for safety and health into contracts and tendering materials. Research, publications and guidelines on safety and problems within the working environment in the construction industry primarily focus on contractors and the working environment during the construction phase. Traditionally, it has been the sole responsibility of the contractors who employ the construction workers and the working environment legislation supports this (Gambatese & Hinze, 1999; Hinze and Wiegand, 1992). A series of research analyses provide examples on how designers and planners generally do not view it as their responsibility to consider the safety of the construction workers. (Hinze and Wiegand, 1992; Gambatese et al, 2008; Toole, 2002); "The initial premise is that clients and designers have been slow in taking up their responsibilities. Construction work covers many activities, techniques, materials and hazards and it is this diversity that increases the probability of accidents occurring (Baxendale et al, 2000; Thorpe 2005); and the Clients have a positive role to play in lowering injury rates and influencing contracts (Smallwood, 1998).

In a series of research and development projects terms such as "safety design" and "total safety management in construction" have gained a footing. In these projects it is pointed out how much the designers actually influence safety during the construction phase and how decisions, design and construction has a direct impact on the safety of the construction workers (Hinze and Wiegand, 1992; Gambatese & Hinze, 1999; Thorpe, 2005). Safe design in construction is defined as the deliberate decisions concerning the safety during construction, which have been made during the design phase with the purpose of reducing the risks facing the construction workers' (Toole et al, 2006). When asked what safe design or safe buildability is a series of different ideas were offered which are generally concerned with purely technical directions, but also with planning methods (Toole et al, 2006; Thorpe, 2005; Frijters & Swuste, 2008). An example of this could be, among others: "Tools for Construction Safety Design" (The Construction Industry Institute, 2009) containing over 400 design proposals. England has extensive material on The Safety and Health Executive's homepage (UK HSE, 2009) and in Australia they recommend a special design review form called CHAIR (Workcover, 2001).

The problem is that the participants in the construction design, both architects and engineers, do not know what, when and how to do it and they do not even look for information in order to rectify this lack of knowledge. There seems to be a need for formulating a best practise in which the designers, planners and contractors can seek inspiration for their attempt to minimize the risks of the construction process.

The problem we have seen is that safety has not found its practical use in the building project's organisation and management forms in a sufficient scope. The purpose is, therefore, to demonstrate in a normative manner how safety can be integrated in the Building Delivery System.

## **2. METHOD**

In the attempt to illustrate to designers and planners how safe design could be obtained in more specific terms the model for the project delivery system was chosen from the lean construction area. The designing process is covered by 7 phases represent 1.purposes & program, 2.disposition & design criteria, 3.design concepts, 4.process design & pre-project, 5.main project & product design, 6.supplier project & detail engineering, and 7.preparation of construction, logistic, communication etc. (Ballard, 2000; Koskela, 2002)

The working environment problems have to be a concerning element for both goals, values as well as when the design and construction plans are being scrutinized. The philosophy is, that knowledge about which kind of

safety and health problems that mostly appear in construction, has to be knowledge integrated in the design phase in order to be minimized as much as possible in the design. However it is obvious that you cannot eliminate all risks, but at least you can identify which risks that remain. These risks have to be taken care of during the executing phase and be implemented in the final plan for safety and health before the executing phase begins.

**Most common risks in construction** (Jorgensen et al 2010, 2009, 2008):

- The risk of falling from heights when working on ladders, scaffoldings, roofs or wherever working close to level differences
- The risk of falling on same level when walking on untidy surfaces, close to holes, uneven surfaces or slippery areas
- The risk of being hit by machinery or hand tools while working with different technologies
- The risk of being hit by falling objects either from work taking place in a higher level or from elevated objects e.g. cranes
- The risk of being hit by a vehicle when walking close to trucks or moving construction equipments
- The risk of being hit by falling material which is handled manually by workers
- The risk of back pain or other types of musculature disorders when lifting heavy material or working in difficult working positions
- The risk of brain and lung diseases when working with dangerous substances or dusty materials
- The risk of cancer when working with cancer related substances and materials like asbestos and PCB
- The risk of vibration white finger when working with vibrating tools The risk of having vibrations of the whole body when working with large vibrating machinery
- The risk of hearing damages when with noisy equipment
- The risk of stress when working under high time pressure
- The risk of poisoning when working with polluted soil or water
- The risk of drowning or lack of oxygen when working near water or in wells
- The risk of being buried when working close to steep slopes or bunch of materials
- The risk connected to work with explosive materials, high voltages or ionization conditions

**General principles for prevention (DWEA 2012)**

- Evaluate the risks.
- Preventing the risk at the source.
- Adjust the work to the workers, especially the design of the workplace, the choice of equipment and the working methods. Avoid monotonous work and work in fixed rhythms.
- Take the technological development into consideration.
- Substitute dangerous work, substances and equipment with something less dangerous.
- Make plans for safety and health as a coherent whole, which include technology, work design, working condition, social relation and risk factors in the working environment
- Make precautions against collectively prevention instead of individual prevention
- Be sure that all workers have got a proper instruction of safety in their work

The method for filling in knowledge of what to do and how to do it with regards to integrating safety in the design phases was an iterative focus interview of professional client consultants and designers about what they are doing, in addition to the decisions they are making in each of the 7 phases. The interviews were carried out over a period of half a year, throughout ten meetings where activities and decision types in the design phases were elaborated on and defined, at the same time as a proposal for integration of the working environment was tested. The method was very simple to ask what the designers were doing in each phases, what kind of decisions they had to do at each step and then find the problems for the working environment that these decisions could create or would be of relevance to take into consideration by the designers. The theory behind this method is also very simple, we had to show how to integrate consideration of the working environment into the work the designers know about and are familiar with. The research group included professional knowledge about safety and health in general and about the construction sector in particular.

The developed guideline was tested in one focus group meeting with a group of 10 designers from different enterprises, including both architects and engineers working with design of constructions. The set up for this focus group meeting was an educational set up, where the participants learnt about the guidelines and was asked to use the guidelines at 3 different cases. The meeting was structured in lectures and practical work with the cases. The evaluation of the results was a direct feedback from all the participants about the usefulness of the guidelines and the needs for development.

### 3. THE RESULTS - AN CONCEPTUAL RE-ENGINEERING

The result of the research presented here is a short description of the guidelines to demonstrate the method and the manner of incorporating safety into the building delivery system as a conceptual reengineering of the construction model with the inclusion of perspectives of safety and health as an integrated part of the construction process.

#### The 7 phases in the design process and safety

By having a description of what is happening, by whom and for what purpose, it is possible to describe in what way to withdraw focus on safety and health.

**Phase 1 - The programme** must contain goals and values for the construction, which means that the client determines the basic values for the construction with regard to: function of the construction i.e. size, location, quality, economy, time frame, etc. It is important at this stage that the client sets a definite level for the safety and health of the construction since it affects the choice of collaborators, contracts, suppliers, organisation et al.

Two significant areas influence this stage – the formulation of the vision and strategy of the construction project and the formulation of the plan for carrying out the construction process.

A vision expresses what the client desires for the construction in terms of character and values. This could be expressed as follows:

- The construction is to be a model project wherein the managerial values, including safety and health at work, are communicated to the collaborators throughout the entire construction process.
- That safety and health at work is a joint responsibility for all parties involved in the construction process, possibly in an alliance where all parties have well defined duties and tasks aimed at improving safety and health at work.

The strategy is an expression of the way in which the client wishes to fulfil his/her vision. This could be expressed as follows:

- That the construction process is to focus on the time frame as well as economy, quality and safety and health at work. This includes minimizing safety and health risks as much as possible during the design and planning phases and is to take place as a purposeful planning of the safety and health process during executing phase.
- That objective and measurable goals are set up for the project considering safety and health during the executing phase, and that risks are prevented by identifying them and planning to avoid them early on in the design phases.
- That an organisation is set up managed by e.g. the client's safety and health coordinator and the head of design and planning. They are to ensure information and knowledge for everyone involved so these can take responsibility and act with regard to the vision for safety and health at work including continuous collection of reports on discrepancies, accidents and near accidents as well as carry out supervision and control e.g. during an audit.
- That everyone involved is motivated towards fulfilling the client's vision for safety and health at work through contracts, bonuses and consequences when the requirements are not met or when they are excellently complied with. This could be carried out by the client's safety and health co-ordinator.

**Phase 2 - The design criteria** contains the general design criteria, but should still be drawn up in such an explicit way that the following processes understand what it is they are to include in their considerations. The conceptual design can even contain very precise information on what is included in the stated goals and values. When considering safety and health at work it could be expressed as follows:

- Building components must be manageable in order to minimise heavy lifting. As an alternative, in cases where heavy lifts cannot be avoided, suitable lifting aids are to always be made available.
- Substances and materials that might present a nuisance to those working with them are not to be used. As an alternative, in cases where use of these substances or materials cannot be avoided, necessary safety equipment is to always be made available.
- The sites and means of access are to provide room enough for the construction workers to apply good work postures. As an alternative, in cases where this is not possible, a special workplace evaluation is to be carried out for the assignment with regard to safety and health.
- Traffic roads and transport forms on the construction site are to be designed in such a way that they create a high level of safety for those who move around and work on the site. Areas for walking and driving could e.g. be kept separate. As an alternative, in cases where this is not possible, a workplace evaluation is to be carried out and necessary safety precautions are to be taken for when unsafe transportation takes place on the construction site.

**Phase 3 - The design concepts** establishes what the building is going to look like, its outer appearance, floor plan, choosing the structural engineering principle, choosing materials and installations. This includes identifying the risks that can create difficulties and that are to be a part of considering the choice of construction, materials etc. The deliberations ought to evolve around whether there are alternative solutions that can minimize the need for specific safety requirements later in the process.

Furthermore, procedures for communication and co-operation between the involved parties throughout the building delivery system could be established here. This could e.g. be a decision stating: that the management of the construction process is to be carried out as a lean project; how coordinating safety and health is to take place etc.

Furthermore the architect puts forward demands for how the client's goals, values and specifications from the programme are to be met. This also includes how to handle the requirements for safety and health at work during both the executing phase and during use and maintenance of the final building.

This is also the most suitable time for determining and describing structural elements as basis for drawing up control charts for quality assurance and similar control charts for safety and health evaluations.

**Phase 4 - The process design and pre-project** includes documentation from pilot studies and possibly of new methods that are to be applied if possible and clarification of specifications, testing materials and inquiring on possibilities and needs with those involved e.g. end users and authorities. Acceptances are obtained from the authorities, it might be investigated what is possible in areas which have not been clarified and the main project is defined. Moreover this includes the first rough sketch of a plan for safety and health and a specification of which actual risks are to be corrected in the main project. In the process design and pre- project the designer's demands are transformed into concrete actions and the overall solutions are determined. Moreover the operational action plans for the execution of the construction project are determined.

To a wide extent this is where the final lines are determined for safety and health. Therefore, it is important that the plans for product and process with regard to requirements and choices in relation to the consequences it might have on safety and health during both the executing phase and later maintenance of the building are thoroughly looked through during this phase. All structural elements must be scrutinized at this stage ex. the ground, the materials, the building site etc. that have been sketched or decided upon. Every part of the construction project is looked over in order to assess the risks concerning safety and health at work based on the safety list for structural elements. There is a definite need for defining buildability and especially safe buildability during this phase and it is therefore necessary to enter into dialogue with the entrepreneurs, who are going to make the construction. The demands stated in the design criteria that may not have been fulfilled in the design concept are to be incorporated in the planning of the executing phase at this point and solutions must be found. The process design very much includes managing and operating the processes – both vertically and horizontally in relation to the entire chain of deliverables being both planning element deliverables and detailed planning deliverables as well as product and material deliverables and output in the form of e.g. the execution of a task.

The overall lines for the process during the execution of the project are added to the demands for the process to be plannable via e.g. lean methods.

**Phase 5 - The main project – product design** includes the detailed description of how to solve and carry out the construction assignment. During this stage, the main plan, general drawings, building component drawings, detail drawings and detailed descriptions explaining the demands for materials and for carrying out the tasks are drawn up. This is also the phase during which the final plans for safety and health for the executing phase are determined as well as the basis for those workplace evaluations that are to be carried out by the ones working on the project regarding risks that have not been addressed during the design and planning phase.

In connection with the main project the construction has to be scrutinized with regard to buildability, execution and safety.

Detail drawings and detailed descriptions are drawn up in which links between the various building components and mounting details, including their function and buildability, are specified, controlled and determined. In connection with this it has to be evaluated which risks it has not been possible to eliminate during the design and planning phase, and which therefore have to be addressed through precautionary measures during the execution of the construction project. The evaluation will result in requirements for the ones involved in the project to implement the identified measures. The risk assessment will include the client's values e.g. time frame, price, quality and safety and health at work. This, in combination with Lean Construction's 7 preconditions for a healthy activity, ensures that obstacles do not arise during the execution of the construction project.

**Phase 6 - The supplier project and detail engineering** includes how to determine which materials, outputs and possibly prefabricated building components are to be delivered by whom and when. Choices have to be made concerning choice of product, choice of suppliers and thoughts on delivery times, mounting sequence and mounting method.

This also includes thoughts on the risks possibly associated with handling and processing before mounting and a demand for the suppliers to be a part of the on-site work because of their specialized knowledge about the products.

A series of analyses show that the suppliers are the primary source of new information on products and materials for others involved in the projects. The suppliers are responsible for the set-up and content of the products, and the suppliers are also responsible for providing the product buyers with satisfactory and uniform information on the products such as statutory manufacturer's manual.

**Phase 7 - The production preparation** includes how to ensure that all goals, requirements and specifications are fulfilled in the material describing what is to be built. The project material must be evaluated in order to assess the buildability and to determine the actual methods for executing the construction project. This is also the stage at which the collaboration between the client's safety and health coordinator, the planning manager, the construction manager and the contractors is developed. They are to coordinate and communicate the safety and health measures during the executing phase. The client's safety and health coordinator for design and planning is to hand over the process to the safety and health coordinator for the executing phase. It may be the same person, who carries on the work, but often it will be two different safety and health coordinators, since the safety and health coordinator for design and planning needs to possess special competencies within planning and design operations while the safety and health coordinator for the execution phase needs competencies within executing the construction process. Furthermore the safety and health coordinator for the execution phase needs to possess special skills in facilitating co-operation and motivation among those employed at the construction site.

## **Management of the process**

The design project has to be managed and normally is by a project manager. The practical experience shows that the process can be supported by a line of workshops, where the project is discussed by the client, the designers, the constructors and maybe also the end user.

1. A workshop at the very beginning could help the client to formulate the values and ideas for the programme - phase 1, as a political plan for the building.
2. A workshop for the planning of the design criteria – phase 2 could help the project manager to create the structure for the design process.
3. A workshop for the design concepts – phase 3, could help coordination of the requirements for the buildability of the construction
4. A workshop for the process design and pre-project – phase 4, could be the basis for an analysis of the buildability of the construction

5. Workshops for the main project and the supplier project – phase 5 and 6, must be the place for scrutinizing of all the details for fulfillment of the requirements and the buildability of the construction.
6. A workshop for the production preparation – phase 7, where all preparations for the construction at the site can be finalized and make agreement for including plan for safety and health and how the organizing of safety has to be carried out while constructing the building.

Clear goals from the client and engagement and commitment from the project manager towards safety and health is a must through the processes. As a help for the project manager to work systematically with safety and health a line of checklist has been developed.

It may be appropriate to use a number of checklists throughout the different phases, especially from phases 3-7 and thus gain an overview of the tasks so the working environment is fully illuminated in all phases as a part of the total project. In addition, a review and control plan are drawn up, where the construction is structured in process units, naturally coherent building parts, e.g. based upon a division corresponding to building operation. 5 checklists are drafted for use in phases 3-7. Table 1 illustrate one checklist for control of the building envelope at the design concept phase (Jorgensen et al 2009)

Table 1, illustrates a proposal for control of the building envelope at the design concept phase

<b>Phase 3</b>	<b>CONTROL REPORT FOR THE DESIGN CONCEPT</b>	<b>Date:</b>
<b>Subject</b>	<b>Mounting instruction / risk focus</b>	
<b>Process unit</b>	<b>Climate shield</b>	
<b>Purpose</b>	<b>Result requirements for buildability</b>	<b>Activity</b>
1. Material specification	Materials and logistics: a. The material description shall be clear and resource optimising. b. Materials shall be chosen with care, so regard is paid to the working environment with installation and operation of the construction project. c. The materials shall be able to be handled without heavy lifting and unsuitable working positions. d. The materials shall be able to be maintained using simple and secure methods that do not require special safety equipment.	Yes or no?
2. Mounting instructions	Working method and assembly particulars: a. The mounting process shall be thought through and described so that working methods and assembly particulars are simple, logical and safe . b. Technical guidelines and instructions from material suppliers shall be included in the mounting instructions and followed during execution of the work. c. Requirements shall be drafted for a safety and health plan.	Yes or no?
3. Material and logistics	Material and logistics: a. Directions for materials shall be followed while work is performed, and should therefore be procured. b. The transport path for materials around the building shall be analysed and be included in the building's establishment with regard paid to this occurring in a safety related defensible manner.	Yes or no?
4. Personnel	Knowledge and competencies: a. It shall be ensured that all in the project organisation have the necessary building technical knowledge and have the necessary working environment related competencies in relation to attitude and behaviour, including co-operation and communication. b. It shall be investigated whether there is the need for competencies that there are special legislative requirements for.	Yes or no?
5. Building site condition	Requirements for the building site: a. The building site plan shall be drafted so that it fulfils the Danish Working Environment Authority's requirements with respect to establishment, labour conditions, etc. b. It shall be ensured that there are safe entrance conditions for manpower as for the transport of materials, in addition to waste management.	Yes or no?
6. Planning and follow-up	Surrounding world, decisions and requirements: a. It is appropriate that all in the project organisation have a common goal and basic values that support process orientation, co-operation, as well as preventing functional breakdown and sub-optimisation. b. Communication and co-operation should be organised in a meeting form that ensures the building site's organisation, working environment, logistics and co-ordinated process and time planning.	Yes or no?
7. Preceding activity	Transfer from other contractor: a. The fulfilment of result requirements for subsequent contractors shall be ensured through quality assurance of the preceding activity. b. There shall be a quality related connection of the quality requirements so that they appear measurable and clear.	Yes or no?

The 5 checklists:

1) A checklist for phase 3 the design concepts that concerns the project proposal and outcome requirements regarding project feasibility where the outcome requirements must be formulated on the basis of an implementable perspective. This is the requirements for the safe buildability.

2) A checklist for phase 4 the process design and pre-project that concerns analysis of project feasibility, where the analysis must contain a review of the assembly process. The assembly specification of this review must describe the process and the relationship between the building components. This is the analysis of the safe buildability.

3) A checklist for phase 5 the main project and fulfilment of requirements regarding project feasibility, building components and elements where it must be ensured that the selected solutions for the building components and elements satisfy the stipulated outcome requirements. This is the control and scrutinizing of the safe buildability with the quality review.

4) A checklist for phase 6 the supplier project and fulfilment of requirements regarding system solutions, where the suppliers of the system solutions and component projects must provide assembly specifications that satisfy the stipulated outcome requirements. There will be a risk control that will be conducted concurrently with the quality review.

5) A checklist for phase 7 the production preparation, project review and fulfilment of requirements, where the project review will be conducted in conjunction with the final contracting with the contractor and must ensure that the work environment-related conditions are illustrated in relation to the interfaces in the technical specifications. This is the final control and scrutinizing of the safe buildability.

#### **4. DISCUSSION**

A general theme is that architects, designers and planners have not seen it as their responsibility to provide safety during the execution of the construction projects. They have passed on this responsibility to be solely in the hands of the contractors. One explanation is that no teaching about working environment is included in architects or the engineer's education at the universities. Another explanation is that the problems occur at the executing phase and seems difficult to relate to the design phases. The new legislation about the clients and the designers responsibility for safety and health arise a need for new knowledge and guidelines for how to carry out this new responsibilities for the designers. It is this problem that the Danish report on integrating safety and health in the design and planning phase tries to compensate for. But it is to be considered as a small step on the way and it will not suffice on its own. We have, however, not touched upon the difficulties in getting such new ways of thinking implemented in practice. The construction's actors are characterised by being very conservative and a major task waits with introducing and training, as well as motivating. But, it may not base itself on there not being suitable method descriptions and solutions. The significance of the results in this research is a demonstration of how safety and health can be integrated in the construction processes, not as a special viewpoint but as an issue parallel to issues such as quality, costs, time, sustainability etc. that a construction project has to deal with. It is also important that the designers can accept the method as a method they found usable in practice which is a necessary condition for success. The focus groups feedback was that it had been an eye opener for all of them.

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