Learning from safety in other industries

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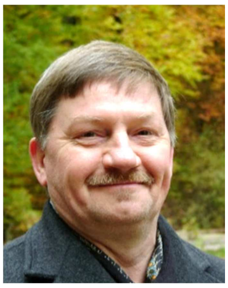

Summary

The Dutch building industry has been shocked by some major structural accidents during the last 10 years with buildings during construction as well as with delivered buildings. Several initiatives were started to improve the safety. In other industries the safety awareness seemed to be more developed. In this article the Dutch building sector is compared with the aviation industry and (chemical) process industry, to see which safety influencing factors can be improved for the building industry. It appears that the risks in relation to a building after completion are fairly low, comparable to the other industries. On the other hand the approach towards safety in the building industry is relatively undeveloped, which gives starting points for improvement.

Key words: structural safety, building process, safety in industries

1. Introduction

The last 10 years the Dutch building industry has been shocked by several major accidents, like the collapse of the steel structure of a theatre in Hoorn during erection and the collapse of 5 balconies of a residential building in Maastricht about 6 months after completion. These events initiated various actions to achieve a building industry that makes safer buildings. [1].
Apart from these initiatives it was suggested that other safety related industries in The Netherlands, like the process industry and aviation might be more developed in safety performance. This lead to the research question: "In what respect can the Dutch building industry learn from aviation and process industry with regard to safety?"

To answer this question a comparative analysis has been used in this research. Aviation, process industry and building industry were studied as cases. They have in common that a distinction between design/build phase and use phase can be made.
This research used an article of Zwaard and Groeneweg [2] on a comparison of several safety related industries as a starting point. Open interviews with participants from companies and supervisors from the government were added to improve the understanding. The interview questions were loosely based on literature on safety influencing variables like the ARAMIS [3] model and Tripod [4] method. Finally some important characteristics of the industries were listed, while several aspects like safety performance were assessed by the authors. Although this method might be subjective, the aim to determine lacking safety factors within the building industry could be obtained.
In chapter 2 aviation, process industry and building industry in The Netherlands are compared on characteristics, risks and safety approach. In chapter 3 conclusions on the comparison will be drawn. In chapter 4 opportunities, threats and current developments are discussed.

2. Comparison industries in The Netherlands

2.1 Characteristics of building industry compared to aviation and process industry

Table 1 summarizes various general characteristics of the compared industries, which will be explained in the text of this paragraph.

Table 1: Comparison of characteristics of building industry, aviation and process industry

Domain	**Structural safety in building industry (design&build)**	**Structural safety in building industry (use)**	**Safety in aviation (design& build)**	**Safety in aviation (use)**	**Safety in process industry (design& build)**	**Safety in process industry (use)**
Primary process	Design and execution of a building	Use of building	Design and building of airplanes	Transport by air	Design and building of chemical installation	Producing by chemical reactions
Orientation	National	Local	International	International	International	idem
Level of organization sector	Low	Very low	High within company	Very high	Average, high within company	idem
Collaboration per project	Variable partners	Not applicable	Longterm partnerships	Longterm partnerships	Selected partners	idem
Complexity process	Low	Low-High	Average-high	High	Very high	idem
Accessibility sector	High	Very high	Low	Low (personnel) Average (passengers)	Low	idem
Relevant level of education	Average	Low	High	High	High	idem
Complexity object	Object unfinished	Low-High	Object unfinished	Very high	Low-high	idem
Exposed to elements (weather)	Yes	Yes	No	Yes	Not always	Yes
Preparation object	Analysing Modelling	-	Analyzing Simulating Prototyping	-	Analyzing Simul./ modeling Small experiment.	-

For the three industries a more or less clear distinction can be made between a design&build phase and a use phase, although for the process industry these phases are more interrelated. Both in the design&build phase and in the use phase a primary process can be perceived. The use phase of a building consists of the accommodation and protection of persons. In aviation the use is about transport by air and the process industry focuses on the manufacturing of products by chemical processes.

2.1.1 Orientation, level of organization and collaboration

The building industry is nationally orientated with respect to the design&build phase. Most of the contractors and engineers do projects within the Netherlands. Clients (users of a building) are most of the times locally oriented.
Forms of collaboration of building participants are often one of a kind and non-repetitive. The level of organization is low for both contractors and engineers. Usually the level of organization of users is low too, except for large companies and organizations with professional technical management. An unlimited amount of subcontractors may be apparent.
Within the other industries a more global orientation is observed. Aviation is highly organized and regulated within ICAO (International Civil Aviation Organization). The main participants of the chemical process industry are multinationals, which are highly organized on company level.
Durable forms of collaboration are present in both industries with long term partnerships or selected partners and a limited amount of subcontractors.

2.1.2 Complexity building process, accessibility sector and level of education

When process complexity is defined as the proneness to failures due to small deviations, the complexity of the building process of buildings can be considered as rather low. It consists of many relatively easy actions that can be done without advanced education. However, considerable complexity can be observed in the current building industry, by the presence of many uncoordinated parties, where fragmentation is mentioned as a possible threat [1]. The use process on the other hand is less complicated than in aviation and process industry; the processes within the last two industries are more prone to failures due to small deviations and are valued as (highly) complex.

The accessibility of the building sector is relatively high. There are no restrictions to start as e.g. a contractor, probably because the process complexity is considered to be low. Only recently a voluntary registration of engineers has started, with requirements for education. For users there is no limited access and there are no education criteria. For the other sectors a more regulated accessibility of the sector is apparent, which can be explained by the high level of process complexity.

2.1.3 Complexity objects and preparation before building object

Buildings can be very simple (one storey house) to more complicated (nuclear factory or free formed blob architecture). In general they are less complex than most airplanes and chemical plants. For instance in airplanes a demand for innovative materials is apparent to reduce weight and save fuel costs. Furthermore an abundant amount of high-tech installations is used within airplanes and chemical plants.
In the building industry most of the time the preparation before building is limited to analyzing and modeling, for most buildings are not repeated. Therefore most buildings are in fact prototypes. In aviation and process industry often simulation and prototypes or experiments are used to prepare for the building of the objects (airplane or chemical installation). Furthermore airplanes are entirely built within a protected area, which improves the probability of a satisfying quality. Buildings on the other hand are usually built while exposed to weather elements.

2.1.4 Conclusion characteristics

It can be concluded that the building industry is rather traditional and low profile, compared to other industries, although increasing complexity of the building process have been observed.

2.2 Safety risks and consequences

Table 2 presents various information on safety risks and consequences of the compared industries, based on Zwaard and Groeneweg [2].

2.2.1 Maximum impact and probability of failure

The possible maximum impact of accidents during execution of a building seems to be limited. Most of the times just only part of the building will collapse and only limited number of persons are present during execution. After completion usually more persons are present in the building, thus the maximum impact can be higher.
An airplane crash is terrible, but usually the consequences when it concerns a testing flight remain limited. During operation the consequences might be more extensive, for a relatively large number of passengers might be involved. Consequences might be extensive when an airplane hits an urban area. For instance the Bijlmer disaster in Amsterdam [5] can be mentioned, where an airplane hit a residential building. In the process industry during a small scale test the consequences usually will be limited. During operation the maximum impact can be disastrous, for instance in the Bhopal accident which caused over 1700 fatalities [6].

Table 2. Comparison of safety risks and consequences

Domain	**Structural safety in building industry (design&build)**	**Structural safety in building industry (use)**	**Safety in aviation (design& build)**	**Safety in aviation (use)**	**Safety in process industry (design& build)**	**Safety in process industry (use)**
Examples of risks	Collapse of building during erection	Collapse of building	Airplane crash during test flight	Airplane crash	Explosion	Explosion
Max. impact of credible accident	Low	Average	Low	High	Average	High
Probability of failure	High	Low	Low	Low	Low	Very low
Cause of failure	Design/building	Design/ building	Design/ building	Use/ maintenance (operational)	Design and build	Use/ maintenance (operational)
Responsible persons	Structural engineer Contractor	Structural engineer Contractor (Technical management)	Engineer Contractor	Pilot Flight management Ground personnel	Engineer Operator	Idem
Effect after mistake on	Self and others	Others	Others	Self and others	Self and others	Idem
Effect mistake	Immediate and postponed	Postponed	Postponed	Immediate and postponed	Immediate and/ postponed	Idem

The yearly amount of fatalities during execution of buildings is rather high; there is an increased probability of failure. With an average of 25 fatalities a year (period 2006-2008) and a population of about 500.000 laborers this gives a yearly probability of fatality per person of 50*10^-6 [7]. It should be noted that not all fatalities during the execution phase were caused by structural accidents.
During use of buildings the probability of failure is low. Within the last 15 years only one case, with persons killed during a structural accident of a completed building, is known (cases with fire excluded). This tragic event occurred with the collapse of balconies in Maastricht as mentioned in [1]. With a population of about 16,5 million people there is a yearly probability of fatality per person of: 2/(15*16,5*10^6)=0,008*10^-6, which is rather low.
It can be concluded that for the use phase of buildings the occurrence of structural accidents is rather rare. Most of the problems are already discovered during the execution phase. Additionally a building structure seems to be rather resilient, due to safety factors, robustness of the building and “warning behavior” of structures before collapsing, like cracks and deformations.
Nevertheless sometimes failures with older buildings do occur. An example is the collapse of some concrete balcony slabs of a more than 50 year old residential building in Leeuwarden due to corroding reinforcement [8].
For the comparison with aviation and process industry it can be stated that these two industries are renown for their low probability of failure. The probability of failure in the process industry is slightly higher during the design&build phase, because incident are more likely to occur during shut downs and starting ups.

2.2.2 Causes and responsibilities

A structural failure of a building is usually initiated by mistakes within the design or execution phase. The responsible persons are most of the times structural engineers or builders. The effect of the cause usually turns up later and influences other people than the responsible persons. This is the case for failures of buildings during erection and after completion.
For aviation it is possible that airplanes crash due to design or execution errors during the test phase, though the effect of a design or execution error might turn up later. In the operational phase the pilot can be effected immediately by the consequences of his personal mistake. The same argumentation is valid for the operators within the process industry, although the effects of their errors might be revealed later as well; accident related health problems might occur even years later.

2.2.3 Conclusions on safety risks and consequences

It can be concluded that the safety risks within the execution phase of the building industry are higher than the risks within the use phase. The last seem to be comparable to the safety risks of the other industries. The maximum impact of a failure in the process industry is higher than in the building industry and aviation. The causes of accidents in the building industry usually originate for both phases in the design and execution phase. For aviation and process industry operational mistakes in the use phase are the most determining for failures.

2.3 Approach towards safety

In table 3 the approach towards safety is compared on several variables. Its starting point was the comparison of Zwaard and Groeneweg [2].

Table 3: Approach towards safety

Domain	**Structural safety in building industry (design&build)**	**Structural safety in building industry (use)**	**Safety in aviation (design& build)**	**Safety in aviation (use)**	**Safety in process industry (design& build)**	**Safety in process industry (use)**
Importance risk analysis	Average	Very low	High	High	High	Idem
Importance checking (internal)	Average	Very low	High	High	Very high	Idem
Importance checking (external)	Average	Very low	High	High	High	Idem
Focus checking by government	Product	Hardly any control	System	System	System	Idem
Certification/registration persons	Voluntary for engineers	No	Yes	Yes	Yes	Idem
Importance protocol	Low	Very low	High	Very high	High	Idem
Attitude towards changes	Improvising	Improvising	Protocol	Protocol	Protocol	Idem
Analysis of accidents	Poor	Poor	Very extensive	Very extensive	Extensive	Idem
Development knowledge infrastructure sector	Low	No	High	High	Average	Idem
Safety culture	Pathological/ reactive	Pathological/ Reactive	Proactive	Proactive	Reactive/ calculative	Idem
Current Attention to Human factors/Technical issues/ Organizational items	H+-/T+/O-	H--/T+-/O--	H+/T+/O--	H+/T+/O--	H+-/T++/O+	Idem

2.3.1 Risk analysis

For all industries a risk analysis can be made for the design&build phase or the use phase. For the design&build phase of small buildings a risk analysis is often lacking; for more complex buildings usually some kind of a risk analysis will be performed. For the execution phase often a safety and health analysis has to be done. Within the use phase of buildings this analysis is underdeveloped for most proprietors do not perform structural risk analyses at all.
For aviation and process industry risk analysis is an inexticable part of the process.

2.3.2 Control and certification

Internal control by colleagues is rather important in the building industry during design and execution, though it is not always performed. In the use phase this control is generally non existent. On the other hand for aviation and process industry this control, for which approaches are provided by protocols, is very relevant and often obligatory.
External checking is of importance for all sectors, except for the use phase of buildings where external checking is usually absent. However, after recent incidents with façade panels and flat roofs of existing buildings, municipalities have paid more attention to checking of existing buildings [9],[10]. External checking within the process industry is of slightly lower importance, for the internal checking in this sector is decisive.

Checking by the municipality concentrates on the product within the building industry: the building and its components. For other sectors and for the building of infrastructures, like bridges, system checking by the government is more common.
System certification within the building industry of buildings is not usual. The importance of protocols, especially in case of changes, is higher in aviation and process industry than it is in the building industry. In the opinion of the authors the building industry can be characterized by improvisation and fixing when unexpected alterations or aberrations appear.
Certification of individual employees is a rather recent phenomena within the building industry. Builders should apply for a safety certificate; structural engineers can apply for a voluntary registration, if they do obtain sufficient education and experience.

2.3.3 Accident investigation and knowledge transfer

When a failure occurs in a sector, research is done on the causes of the accident by private and public parties. The research within the building sector is usually less extensive than research in the other sectors. A positive development is the initiative of a platform structural safety where cases of building failures are analyzed even on organizational factors. Furthermore this platform offers a confidential registration system for building failures.
Within the loosely organized building industry knowledge transfer is limited, especially during the use phase. The aviation industry developed a more structured knowledge infrastructure with for instance a database on failures. The knowledge infrastructure in the process industry is valued as average for various knowledge management systems exist apart from each other.

2.3.4 Safety culture and approach

Objective statements about safety culture are hard to make. Hudson [11] proposed a Health, Safety and Environment culture ladder, from less to more advanced levels (increasing from pathological, reactive, calculative, proactive to generative). This categorization is indicatively used by the authors of this paper. The building industry can be considered pathological to reactive. Pathological, because alterations from standards do remain until they are discovered by authorities or management and changes are required. Reactive, because a problem normally will be fixed after an incident occurred.
Within aviation the culture seems to be more proactive. There is a long experience with registration of failures, to avoid similar accidents happening in the future. The process industry tends to be more calculative; for continuity it is essential to work on safe processes, whereas the added value of measures is balanced with the accompanying costs.

With regard to the safety approach a comparison is made on the aspects that are currently paid attention to: human factors, technical issues or organizational items. In all industries technical issues will get a lot of attention. Within the building industry some attention is given to the education and safety awareness of builders (human factors). However, attention for organizational issues stays behind, especially with regard to the problem of fragmentation.
The same applies, in a lesser way, for the aviation industry, where systems engineering is common practice to cope with organizational issues, whereas the need for a central responsible person was mentioned by one of the interviewees. It seems that within the process industry abundant attention is given to individuals, technical solutions and organizational factors. Fragmentation in this industry is dealt with by a central responsibility for the plant manager.

2.3.5 Conclusions

It can be concluded that the safety approach within the Dutch building industry is underdeveloped compared to the other industries, for the role of control is smaller, the importance of risk analysis and failure analysis after an accident occurs is smaller, there is hardly no attention for system certification per project and just small attention for certification of individuals, the importance of protocols is low, the safety culture seems to be reactive and there is too little attention for organizational features

3. Conclusions of comparison for the building sector

In this paper aviation, process industry and building industry are compared, in an attempt to draw safety lessons for the building industry.
With respect to the various characteristics, it can be concluded that the building industry is rather traditional and low profile, although developments have been observed.
With respect to safety risks and consequences, it can be concluded that the risks within the execution phase are higher than the risks within the use phase. The last seem to be comparable to the safety risks of the other industries. The causes of accidents in the building industry generally originate in the design and execution phase of the building process.
Furthermore, it can be concluded that within the Dutch building industry the approach towards safety is underdeveloped compared to the other industries.
Finally it can be concluded, that due to a relative high probability of failure and an underdeveloped safety approach, the building industry during execution needs the most attention.

In addition to the conclusion that the execution phase needs most attention, there are some signals of increasing risks within the use phase due to:

- more complex buildings since computer applications allow for free form architecture
- inferior / decreasing building quality of current buildings between 40 and 60 years old
- an increasing amount of building parties involved leads to an increasingly complex building process

4. Discussion

In table 4 some safety threats for the Dutch building industry, derived from the comparison, are presented with some current initiatives or opportunities dealing with these threats. There still remain some points for improvement;

First, attention is needed for the culture within the building industry. In the opinion of the authors it is characterized by fixing only after a problem occurred, whereas a structure should be good at once. It might be beneficial to apply restrictions for access to the building industry in the form of demands on experience and education.
Second, attention should be given to the quality assurance of the building processes and the role of protocols. The quality assurance has to focus on effective and efficient risk analysis and control.
Third, an improvement in coordination between several building parties is necessary. Some development in chain integration have been observed, but this is still a first step.
Finally a more international orientation would be beneficial to obtain useful ideas of other countries and industries for the building industry, especially when complexity of designs will increase.

With regard to the research question: “In what respect can the Dutch building industry learn from aviation and process industry with regard to safety?” it can be stated that the building industry can learn from the approach towards safety of the other industries, especially for the building phase, although the differences in characteristics have to be taken into account.

Table 4: Safety threats, opportunities and initiatives in Dutch building industry

Aspect	**Safety threats**	**Current opportunities / initiatives**
Characteristics	Orientation is too national	-
	Every project with different partners	Chain integration: working on several projects with same partners
	Users do have scarcely any structural knowledge	-
	Exposed to weather elements	Prefabrication
	Hardly no experiments or full scale modeling in preparation for usage phase	BIM and 3D modeling: virtual prototyping
	Accessibility of the sector is too easy	-
Risks and consequences	Responsible persons in design & execution phase are not responsible in the use phase	New contract forms like DBFM (Design-Build-Finance- & Maintain)
Safety Approach	Analysis of risks is underdeveloped	-
	Role and way of control is underdeveloped	Attention for alternative ways of checking by municipality
	Application of system certification within a project is lacking	-
	Protocols dealing with changes are lacking	-
	Certification of individuals is scarce	Certification of individual structural engineers
	Analysis of accidents and communication to the building sector is underdeveloped	Analysis of failures by the Platform Structural Safety
	Knowledge infrastructure is underdeveloped	Attention for the quality of education
	Safety culture is less advanced than other industries	-
	Attention for organizational factors is scarce. Threat of fragmentation is apparent.	Compendium Structural Safety with a proposal for a useful allocation of responsibilities between parties [1]

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