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Causes of Damages in Swedish Buildings

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Abstract. *Damages, failures and functional defects in buildings create high cost for the owner and the society. It is important to determinate the causes of damages in order to limit the costs. This paper presents the causes of 1105 different damages from a technical perspective from 265 real damage investigations. In general, the results show that; 1. Rain and snow was the most common moisture source cause damages, 2. The number of damages caused by wet concrete and PVC or linoleum flooring may be overestimated. 3. A significant number of damages were caused in details where different materials connect to each other, 4. A high number of damages were linked to wear and tear and poor maintenance. 5. Causes of damages occurs in all phases of the building process but most of them were deemed to occur in the management and on-site construction phase. 6. Most of the damages were caused by building owner or their facility trustees.*

Keywords: *Damages and defcts in buildings; Moisture damages; Causes of damages;*

1 Introduction

1.1 Background

It's well known that damages, failures and functional defects in buildings create huge costs for the owners and the society. The yearly cost in Sweden concerning these damages was expected to €5,9-€7,3 billion (Boverket 2018). Most of the damages are linked to mold, moisture or poor indoor environment (Boverket 2018). Damages, failures and functional defects are further on named only as *damages* if not specified in detail.

Since most of the studies we have found in the area were carried out as case studies or by interviews and questionaries, it is difficult to get detailed technical information and statistics about damages. Many studies focus on costs and have a qualitative approach to the cause of damage such as motivation, lack of knowledge, ownership and excludes technical aspects (Boverket 2018, Josephson and Hammarlund 1999, Love and Josephson 2004, Hwang et al. 2009). Only Josephson and Hammarlund (1999) and Love and Josephson (2004) discussed which actor might be responsible for damages, but they excluded the management phase. However, there are also good examples such as the Swedish Water Damage Center, SWDC (1977-2022), presenting detailed data for damages cause by free water, i.e. damages cause by defects in pipes and waterproof membranes. Furthermore, the Danish foundation for damages in buildings and the Danish BYG-ERFA have systems for documentation and information of technical causes of damages in buildings (Byggskadefonden, BYG-ERFA). In order to limit the high amount of damages in the Swedish building stock the technical aspects causing damages as well as when the damages occur and who might be responsible need to be studied.

1.2 Aim

The purpose of this study is to present and compare different technical parameters that cause damages in buildings. The study also aims to identify what actors cause the damages and when in the buildings process causes of damages occur. The presented data can be cross-compared to other parameters, such as the specific damage or the design of the building, and some examples of what could be found using this cross-comparison is presented. In a future step a more thorough cross-comparison will to be done with other parameters using presented data.

2 Prerequisites, Limitations and Definitions

The study is based on 1105 damages, failures and functional defects from 265 real damage investigations that were carried out by six accredited damage investigators during 2014-2021. All reviewed damage investigations in the study are linked to mold, moisture or poor indoor environment. The investigated damages were mainly carried out in the area of Skåne, Stockholm, Uppsala, Gävleborg, Dalarna and Jämtland in Sweden. The study primary focus on complex damages caused during the design-, construction- or management phase. Simple damages caused by free water or floods which in general are handled by moisture technicians were excluded. However, if free water caused a more complex damage, it was included in the study. Limited damages handled on-site during the construction process were excluded.

Notice the demarcation between the cause of damages, which is presented in this paper, and the specifics of damages, as defined and exemplified in Figure 1. The specifics of damages and the definitions for differences between damages, failures and functional defects are described in Mundt-Petersen et al. (2023). The cause of damages can be described by different parameters and depends on the point of view such as qualitative (motivation), technical (building component) and quantitative (costs). The selection of parameters which describes the cause of damages used in this study is shown in Figure 1. Furthermore, each parameter (*Source*) is associated with different variables (*Rain)*. The selection in this study in general focus on technical parameters as opposed to (Boverket 2018, Josephson and Hammarlund 1999, Love and Josephson 2004, Hwang et al. 2009) witch focus on costs or qualitative parameters.

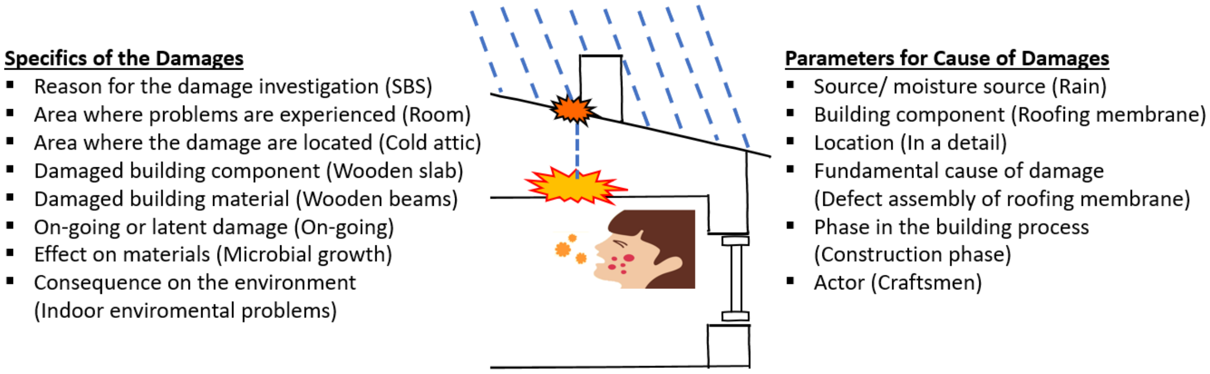

Figure 1. Difference between the specifics of damages and the cause of damage.

3 Method

The 1105 damages were registered in a database. The design and the creation of the database is presented by Mundt-Petersen et al. (2023). In addition to the causes of damages presented in this paper, the database also includes information about the specifics of damages and basic information about damaged buildings. The 1105 registered damages were categorized according to the selected parameters for cause of damage. In addition, some cross-comparisons of the selected parameters were done similar but simpler than the more complex analysis that Wu et al. (2021) did for PCB and asbestos. The results include all registered damages, failures and functional defects in the database. In cases where a single damage was caused by several different variables, all variables were listed. The parameters and associated variables chosen to define the cause of damages in the database are presented in each subheading below.

4 Results and Analysis

4.1 Sources that Cause Damages, Failures and Functional Defects

The distribution of the sources, mainly different moisture sources, which categorize the cause of damage is presented in Figure 2.

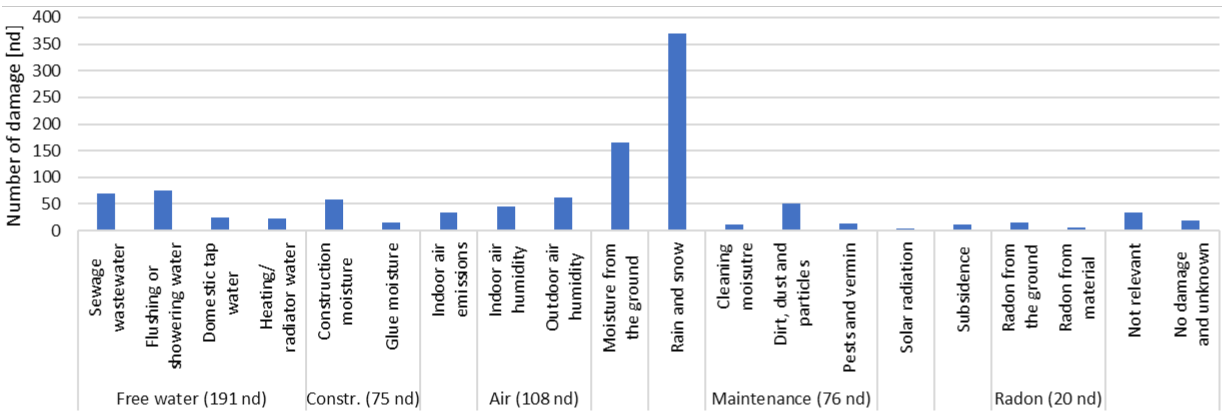

Figure 2. Distribution of the different sources, mainly moisture sources, that caused the damages.

Rain and snow is the most common moisture source that cause damages (369 nd), followed by *Moisture from the ground* (166 nd). Damages caused by free water (191 nd) mainly originates from *Flushing or showering* (75 nd) and *Sewage wastewater* (69 nd). The way published data is structured in SWDC (1977-2022) makes comparisons to our variables for free water difficult. Free water damages are expected to be under-represented in this study since they often are less complicated damages managed by moisture technicians. A significant number of damages are linked to lack of *Maintenance* (76 nd) with the most common variable *Dirt, dust and particles* (50 nd) which should be reasonably easy to remedy. Cross-comparisons show that *Indoor air emissions* (33 nd) are mainly linked to poor ventilation. Damages caused by excess moisture from glued flooring (16 nd) occurs in a design with double PVC or linoleum flooring. Surprisingly only 7 cases of the damages from construction moisture (59 nd) refers to damages where PVC or linoleum flooring was applied on top of insufficiently dried concrete.

This indicate that the number of damages caused by wet concrete may be overestimated.

4.2 Building Components that Cause Damages, Failures and Functional Defects

Figure 3 present what building components that cause the damage. Notice that the actual damage often is located in another building component than the one cause the damage. For example, a defect assembled building component e.g. roofing membrane leaks rain, which further on cause a damage in a wooden beam in a slab in a cold attic as shown in Figure 1.

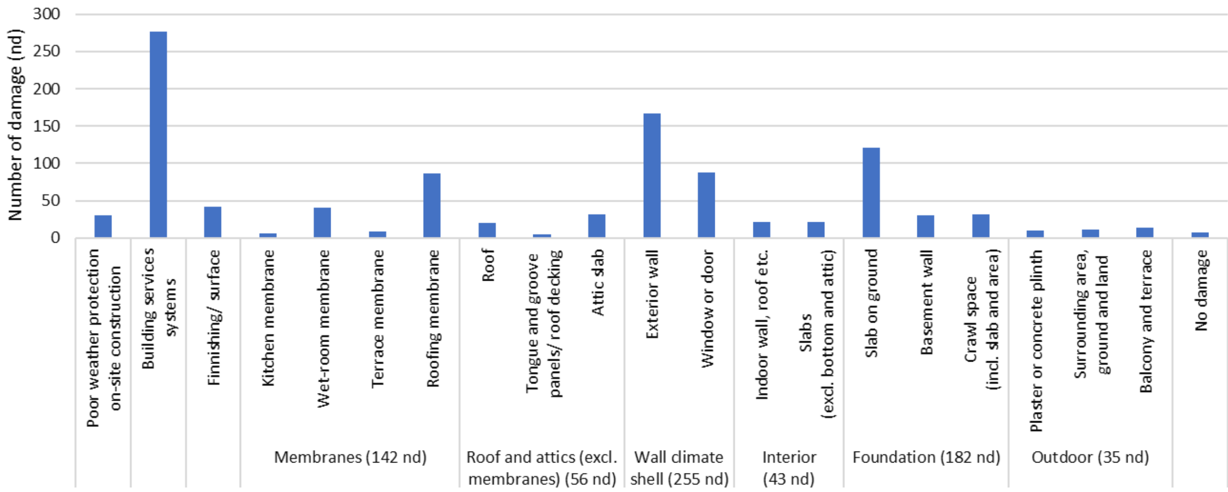

Figure 3. The distribution of the cause of damages in different building components.

A significant number of damages were caused by *Building services systems* (277 nd) and the *Wall climate shell* (255 nd). For the *Wall climate shell*, 234 damages were caused by *Exterior walls* and 123 damages were caused by *Windows or doors*. Most of the 182 causes of damages in *Foundations* were *Slab on ground* (121 nd). Cross-comparing data shows that 76 of the 121 causes of damages in *Slab on ground* were linked to a lack of exterior insulation on the outside of the slab. The limited number of *Crawl spaces* (31 nd), which usually is classified as a high-risk construction, may depend on the number of built designs or the distribution of customers.

Figure 4 shows if the cause of the damage is located in a detail or in the center of a building component or in a buildings services system.

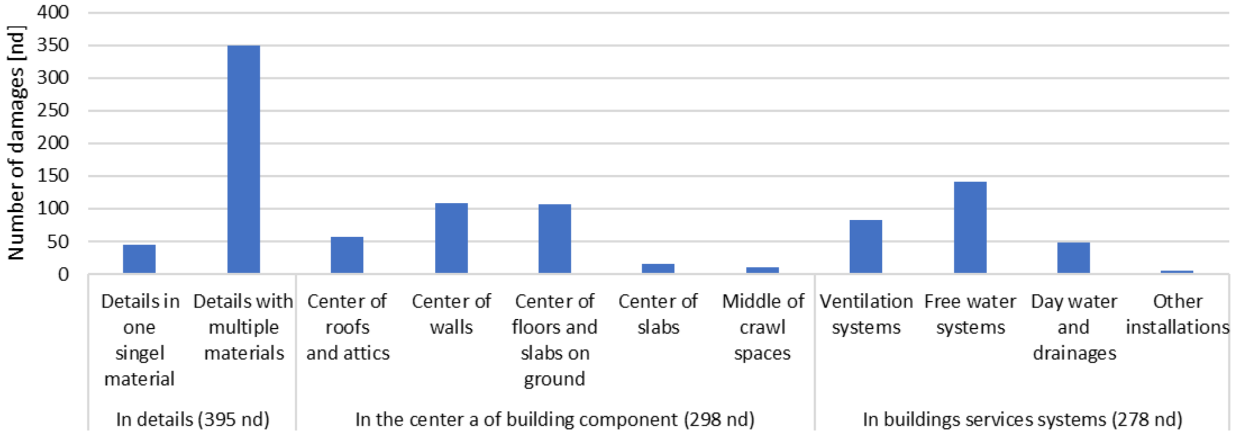

Figure 4. The distribution of the place of cause of damages on different building components.

A significant number of damages are caused by *Details with multiple materials* (350 nd) which show that the design of details is crucial in order to avoid damages. Therefore this variable should be crossed-compared to other parameters in a future step. From the work carried out by SWDC (1977-2022) a high amount of damages caused by *Free water systems* (141 nd) was expected which is also confirmed in Figure 4.

The different number of caused damages from buildings services systems, 277 nd in Figure 3 and 278 nd in Figure 4, is due to that the slope on ground is categorized differently.

Several causes of damages, such as cleaning moisture and maintenance, were excluded inte Figure 3 (56 nd) and Figure 4 (121 nd) since they were not possible to link to a building component and could not be categorized.

4.3 Fundamental Causes of Damages, Failures and Functional Defects Variables

The 17th most fundamental causes of damages are presented in Figure 5. Fundamental cause of damage is here defined as an important necessary underlying condition for the cause of damage to occur, e.g. a defect assembled roofing membraned is a fundamental cause that leads to leakages from rain in Figure 1.

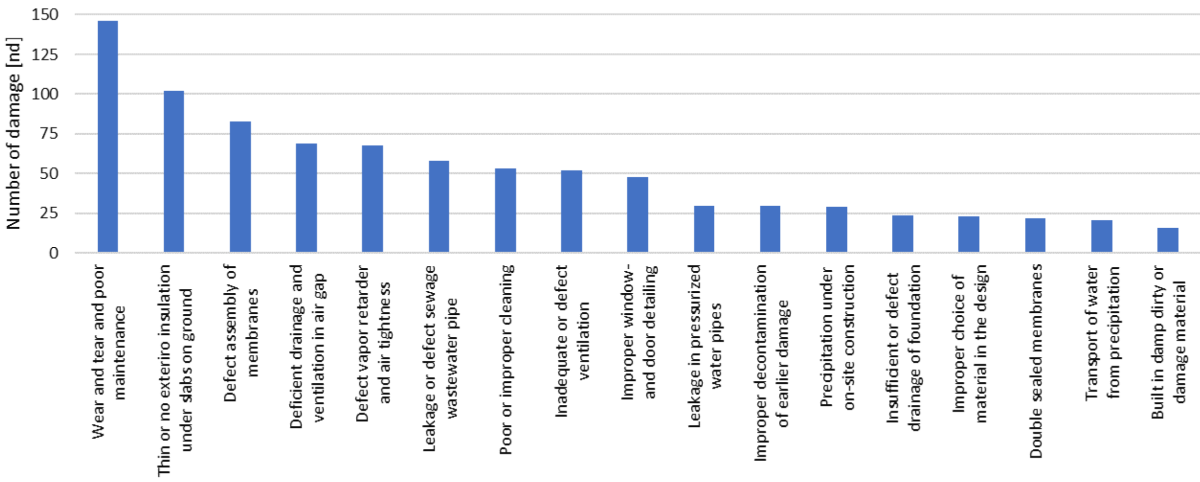

Figure 5. The most common fundamental causes of damages.

The results show that most of the fundamental causes of damages were *Wear and tear and poor maintenance* (146 nd). Several of the most common fundamental causes of damages are linked to the area where SWDC operates, such as *Defect assembly of membranes* (83 nd), *Leakages or defects in sewage wastewater pipes* (58 nd) and *Pressurized water pipes* (30 nd). The risk of damages due to *Thin or no exterior insulation under slab on ground* (102 nd) is well known and was by cross-comparison found to be linked to buildings built before 1980. *Deficient drainage and ventilation in air gap* (69 nd) behind the cladding is also a well-known problem highlighted by the debacle with the EIFS/ETICS façade systems (Boverket 2018, BYG-ERFA, Byggskadefonden, Mundt-Petersen et al. 2013)

4.4 Phase in the Building Process when Damages, Failures and Functional Defects Occur

Figure 6 shows in what phase in the building process the cause of the damages are deemed to occur. It could be discussed if the variables for renovation or rebuilding should be categorized in the *Management phase* or in the other phases.

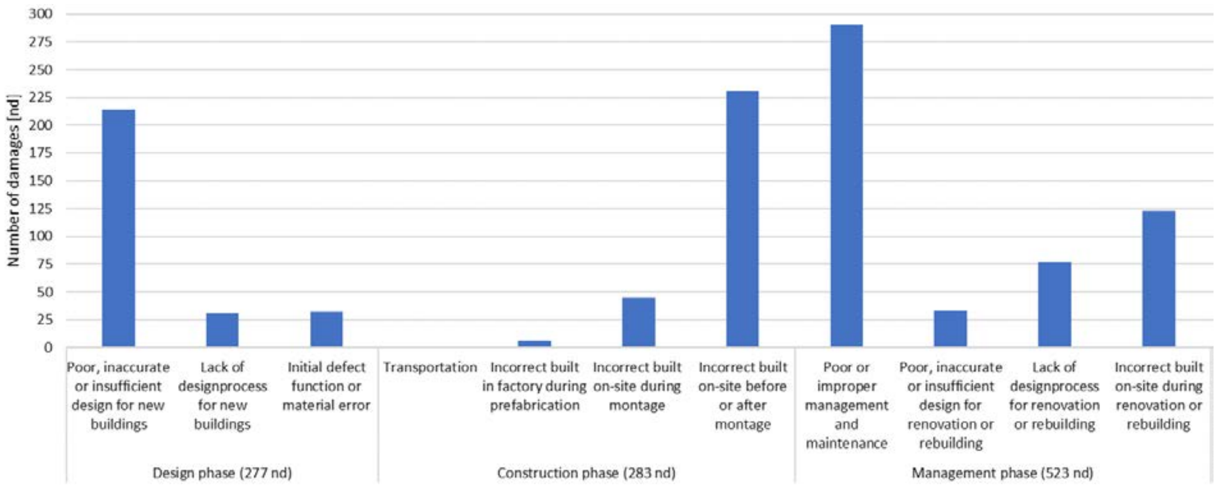

Figure 6. The distribution of in what part of the buildings process the causes of damages occurs.

Given this categorization, the *Management phase* dominates the period when the cause of damages occurs with almost 50 % of all causes of damages (523 nd). *Poor or improper management and maintenance* (290 nd) is the variable which cause the highest amount of damages. The number of damages caused in the *Design phase* (277 nd) and the *Construction phase* (283 nd) are at the same level. *Poor, inaccurate, or insufficient design for new buildings* (214 nd) dominate the damages caused in the design phase. If adding the corresponding variable for renovation and rebuilding (33 nd) there is in total 247 damages caused by poor, inaccurate of insufficient design. Damages caused by incorrect construction procedures on-site before or after montage, i.e. separated from montage of prefabricated elements, caused 231 damages in new buildings and 123 damages during renovation or rebuilding which in total is 354 causes of damages. The significant differences of causes of damages between both *Incorrect built in factory during prefabrication* (6 nd) and *Incorrect built in on-site during montage* (45 nd) compared to *Incorrect built in on-site before or after montage* (231 nd) are notable but must be set in a context and relation to the number of prefabricated buildings and on-site manufactured buildings in the database. It is remarkable that 108 damages, 31 in new buildings and 77 during renovations and rebuilding, were deemed to be caused by an absent design process.

4.5 Actors who Cause the Damages, Failures and Functional Defects

In addition to above presented results it is well debated "who to blame", i.e. what actors cause the damages. This is presented in Figure 7 for the damages in the database. When categorizing "who to blame", the actor which by an action performed the cause of the damage is chosen and other qualitative factors such as motivation, time pressure, poor or corrupt organization and level of competence are not considered in this study.

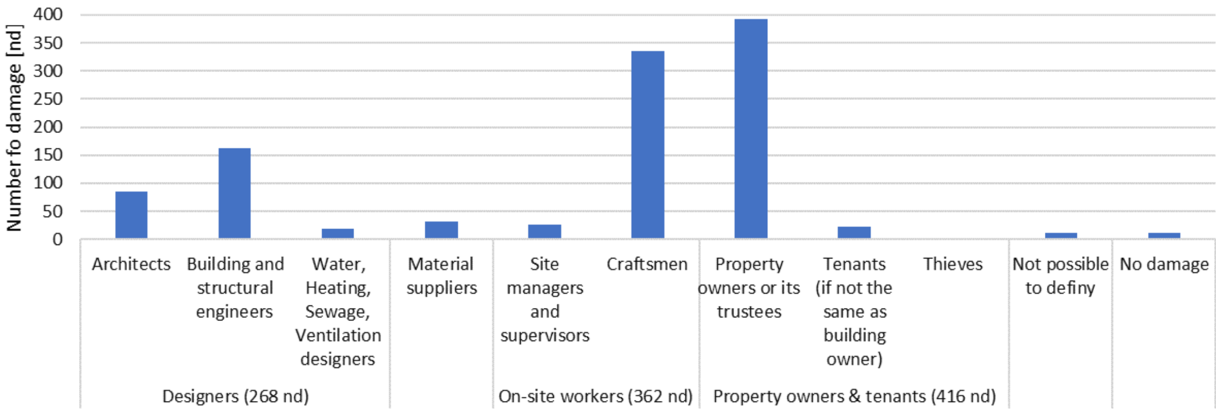

Figure 7. The distribution of in what part of the buildings process the causes of damages occurs.

Property owners and tenants (416 nd), where *Property owners or its trustees* (393 nd) caused the most number of damages. *Craftsmen* (336 nd) dominate the number of damages caused by *On-site workers* (362 nd). Most of the damages caused by *Designers* (268 nd) were by *Building and structural engineers* (163 nd) which is almost double the amount compared to damages caused by *Architects* (86 nd). However, in several cases linked to details it was difficult to determinate if it was the *Architect* or the *Building and structural engineer* who made the design that cause the damage.

5 Discussion

The results were based on 265 damage investigations where 1105 possible damage, failure and functional defects were found. This means that the data were not constructed from random samples and dependent on factors such as complexity, the customers and their ability to pay. As a consequence, damages in single-family houses, simple damages and damages with a low cost to repair is expected to be underestimated in the database. A limited number of causes of damages for a specific variable could depend on both the sample of the database or that there is a limited number of causes of damages in the specific variable. Together, these aspects means that some conclusions should be used cautiously.

Damage investigation as well as registrations for each damage in the database are partly determined by different assessments where all assessments are carried out by accredited damage investigators. Contrary to our initial assumptions, it was in general rather easy to make classifications and clear what cause the damage and what actor caused the damage or when in the building process the cause of the damage occurred. One of the few difficult variables to determinate were if damages were caused by architects or building and structural engineers since it is not obvious in Sweden which of these actors design the details.

When reviewing all causes of damages, the overall reflection is that almost all causes of damages in a technical aspect are currently known and could be avoided in new buildings. It was unexpected, that several damages and causes of damages were found in the same building.

The number of damages in the database is registered with a high level of detail but without regards to the cost to repair or its extent. As a consequence, this made it difficult to compare to other studies that focus on costs and with a lower level of detail such as Boverket (2018), Josephson and Hammarlund (1999) and Hwang et al. (2009).

6 Conclusions

The most important findings from the study are listed below

- Rain and snow are the moisture source that causes the highest number of damages.
- Different building service systems, walls and windows in exterior walls, slabs on ground and roofing membranes are the building components which cause most of the damages.
- The number of damages caused by flooring/glue on wet concrete may be overestimated.
- A significant number of damages are caused by construction details and are found in connections and joints between different building materials.
- Wear and tear and poor maintenance are dominant in fundamental causes of damages.
- Depending on how the different variables are classified, most of the damages occurs in the management phase and the on-site construction phase.
- Most of the damages seem to be caused by the building owners or their trustees. However, craftsmen as well as engineers and architects also cause a significant proportion of the damages.
- It is important but difficult to set proper definitions and find a suitable structure to sort damages and the cause of damages. This is important because it makes it possible to communicate, handle and solve the problems that damages in buildings create.

Acknowledgements

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