XVI International Conference on Durability of Building Materials and Components
DBMC 2023, China
K.F. Li and D.P. Fang (Eds)

Damaged Swedish Buildings

Petter Wallentén[1], S. Olof Mundt-Petersen[1,2], K.O. Anders Joelsson[2] and Mikael Kläth[2]

[1]Division of Building Physics, Lund University, Box 118, SE-221 00 Lund, Sweden,
petter.wallenten@byggtek.lth.se, olof.mundt.petersen@polygongroup.com (Corresponding author)

[2]Polygon Sweden Ldt., Box 1227, SE-171 23 Solna, Sweden,
anders.joelsson@poygongroup.com, mikael.klath@polygongroup.com

Abstract. *Damages with a negative influence on the indoor environment often become linked to high costs. Detailed facts about buildings with damages need to be collected and analyzed in order to be able to reduce the number of damages. This paper presents basic facts, such as design, property ownership and year of construction in buildings where 1105 damages were found. In general, the study gives qualitative indications and cross-comparing to other parameters considering damages and causes of damages needs to be done to obtain better results. Buildings with indoor air ventilated or heated crawlspaces have less damages compare to non- or outdoor ventilated crawl spaces. Damages are more common in buildings with poor exterior insulation in the foundation or a no-drainage and poorly ventilated cladding. In the buildings in the study, schools and local authority owned buildings have a high frequency of damages. A higher number of damages were also found in condominium association owned multi-family houses compared to public tenancy owned multi-family houses.*

Keywords: *Damaged buildings; Frequency fo damages in different designs*

1 Introduction

1.1 Background

Damages, failures and functional defects in buildings, further on named only as damages, with a negative influence on the indoor environment often become linked to high costs. Unfortunately, the number of damages seems to increase in Sweden (Boverket 2018). Detailed facts about buildings with damages need to be collected and analyzed in order to be able to reduce the number of damages. The Swedish Water Damage Center, SWDC, is a good example of how this could be made for free water damage, i.e. damage caused by free water such as leakages in pressurized and non-pressurized pipes and utilities or defects in waterproof membranes (SWDC 1977-2022). Based on their work, guidelines have been created for how to install waterproof membranes and pipes etc. (Safe Water 2021, BKR 2021). Besides the work from SWDC, there is a limited number of reports which present basic information about damages in Swedish buildings (Boverket 2018, Health Agency of Sweden 2017, Anticimex 2014-2022). Unfortunately there is a lack of detailed information about the specific damages or cause of damage in those reports. As far as we know there is no public data regarding damages in Swedish buildings and no activities for feedback about when and what damages occur - like the Danish foundation for damages in buildings and the Danish BYG-ERFA (Byggskadefonden, BYG-ERFA). Since contractors and builders do not share their data of damages, probably due to the risk of bad publicity and lost capital of trust, several studies in the area are carried out by interviews and questionnaires or as case studies (Boverket 2018, Josephson and Hammarlund

1999, Love and Josephson 2004, Hwang et al. 2009).

One way to receive necessary knowledge to handle the problems with damages may be by cross-comparing different parameters for buildings and its damages and cause of the damages like Wu et. al. (2021) did for PCB and asbestos. To do this, basic data of damaged buildings as well as information about its damages and the cause of damages is needed. A collaboration project together with the industry was initiated in order to collect, analyze and compare those parameters for damages. This paper present basic data of damaged buildings collected in the project. Future parts of the project aim to deal with (1) the location of damages, (2) the cause of damages, (3) cross-comparisons of different parameters and (4) artificial intelligence analysis to predict damage.

1.2 Aim

The aim of this paper is to find possible factors which may influence why damages occur. This is achieved by comparing statistics for damaged Swedish buildings regarding different parameters such as: designs, year of built and property ownership, to other factors and published data. In a future step the collected data will be cross-compared to other data for damages and causes of damages in the investigated buildings in order to sort out why, where and when in the building process damages occur.

2 Materials and limitations

This study presents the distribution of 1105 damages in buildings with different designs, climate conditions and year of built. A damage is here defined as when a material or building component has lost its essential properties or not fulfilling needed feature requirements which may cause discomforts. The 1105 nd (where “nd” means number of damages) were received from 265 real damage investigations carried out by six accredited damage investigators during the period 2014-2021. The investigated damages were mainly located in the area of Skåne, Stockholm, Uppsala, Gävleborg, Dalarna and Jämtland in Sweden. The study primarily focuses on more complex damages in the design and exclude possible non-complex damages caused by floods from heavy rain and free water damages which only needs drying. Limited damages handled in the on-site construction process were excluded in this study.

3 Method

The 1105 damages in this study were acquired from a database created for the project. The design of the database was previously presented by Mundt-Petersen et al. (2023). Besides general information about the buildings presented in this paper, the database also contains information about the damages and causes of damages. Studied parameter and its different variables were given and described together with the results.

Registered damages, failures and functional defects were based on information from real damage investigations and not randomly picked. This means that the data is 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.

4 Results, Analysis and Discussion

4.1 Year of Construction

The year of completion (*Year*) for the investigated buildings, where damages were found, and other relevant data and known activities are shown in Figure 1. In case of a known reconstruction, the year of completion of the reconstruction is registered as *Year*.

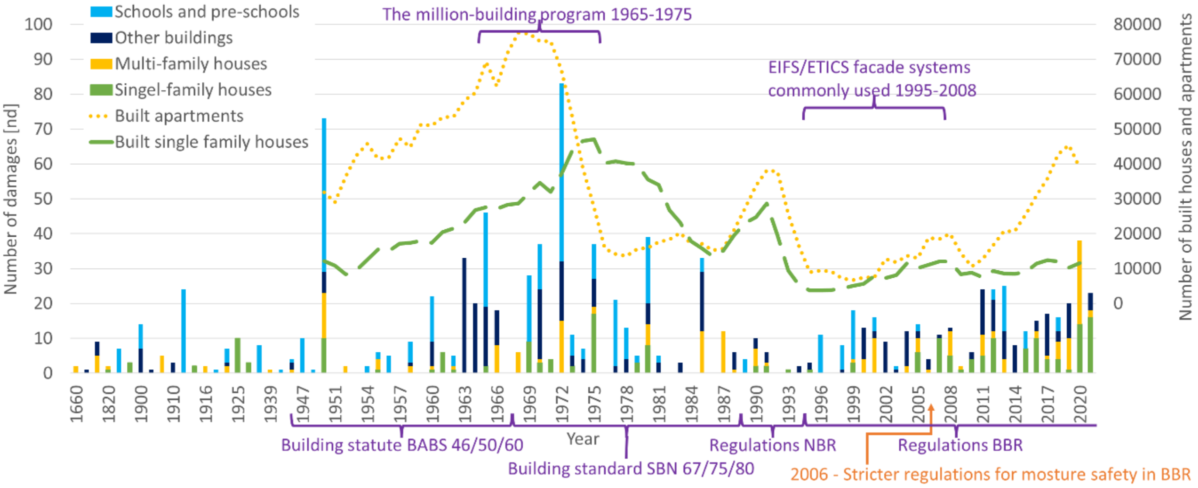

Figure 1. The amount of damage per year in single-family houses (green), multi-family houses (orange), schools and preschools (turquoise) and other buildings (black) compared to actions that may affect the frequencies of damage in buildings and the number of built houses (green line) and apartments (orange line) (SBC 2022).

The results indicate a relatively high number of damages in older buildings and buildings built in the 60s and 70s, which agrees with the findings of SWDC (1977-2022), Anticimex (2014-2022) and Health Agency of Sweden (2017). This may also be expected due to wear and tear as well as the fact that those buildings are old and assumed to have a higher amount of old, degraded details and building materials compared to new buildings. In agreement with Boverket (2018) and SWDC (1977-2022) the number of damages seems to follow the number of built houses. The results show that the variable *Schools and preschools* and *Other buildings* dominates the number of damages in buildings constructed during the period 1963-1980. Furthermore, the relatively lower amount of damage in *Single- and Multi-family houses* during the 60s and 70s indicate that those damaged buildings could not be directly linked to *The million-building program 1965-1975*.

Besides the high number of damages in 1985 there are a lower number of investigated damages until 1999. The decreasing number of new houses being built or the new standard *SBN 80* could possibly create this positive trend. In the late 90s, after implementation of today's *Regulations BBR*, the results indicate that damages have increased. However, *Multi-family houses* tend to have a flat trend even though the construction increased from 2011. The results indicate that that the amount of damage increases in *Single-family houses* from 2005, despite the number of new houses staying at the same level, which is an opposite finding to the Health Agency of Sweden (2017). They reported a lower amount of damage in buildings completed after 2005 (4,1 %) compared to buildings completed 1996-2005 (9,5 %). It is possible that the increased number of damages in the end of the 90s to 2008 could be linked to *EIFS/ETICS façade systems*. This could be further investigated through cross-comparing.

The peak in *1950* is explained by that several buildings without a precise known year of built have been estimated to be built around *1950* (+- 5 years). The peak in *1972* include two investigations of 24 nd and 33 nd. The deviations *1950* and *1972* show that more recorded damages are needed to make a more representative database. The introduction of *Stricter building regulations for moisture safety in BBR* does not appear to have had a positive effect.

4.2 Type of Building and Ownership

The distribution of the ownership and types of buildings where damages were noticed are presented in Figure 2. *Public available buildings* refers to museums, restaurants, cafés, shops, club houses etc. Prisons (1 nd) are registered as *Multi-family houses*. Chapels are registered as C*hurches*. Religious communities (3 nd) are registered as *Community associations*.

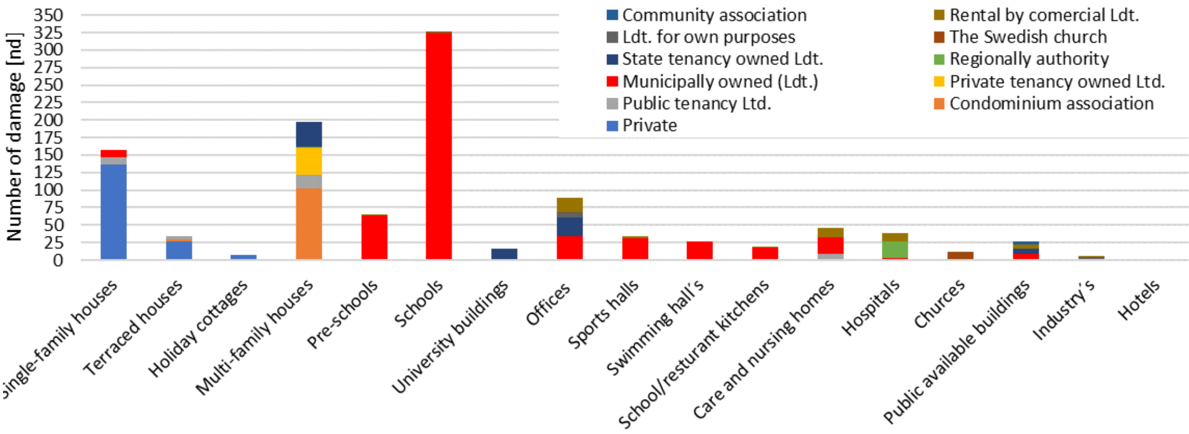

Figure 2. The different types of buildings (x-axis) and its ownership (colors) where damages were noticed.

Figure 2 shows an example of how different parameters, Type of building and Ownership, could be crossed-compared and analyzed. According to the damages, *Schools* (326 nd) and *Preschools* (66 nd) dominate the type of buildings where damages were found (in total 392 nd). Therefore, *Municipally owned* properties (red) dominate the number of damages (542 nd). *Single-family houses* (157 nd), *Terraced houses* (34 nd), and *Multi-family houses* (198 nd) also show a high number of damages (in total 389 nd). A notably high number of damages were found in *Public tenancy* (grey, 10 nd) and *Municipally owned* (red, 10 nd) owned *Single-family houses*. In contrast to statistics from Boverket (2018) and SWDC (1977-2022) a higher amount of damages in *Multi-family houses* compared to *Single-family* houses was noticed, which may depend on that private owners often are treated as low-priority customers.

The number of damages in *Multi-family houses* in *Condominium association* buildings (orange, 103 nd) is higher than the number of damages in *Public tenancy owned Ltd*. (grey, 19 nd), *Private tenancy owned Ltd.* (yellow, 39 nd) and *State tenancy owned Ltd.* (dark blue 36 nd). Although a possibly skewed distribution of the potential customers, our results are in accordance with Boverket (2018) but at the same time is opposite to the Health Agency of Sweden (2017) stating that private owned condominium buildings have a lower number of damages compared to public and private owned tenancy multi-family houses.

4.3 Design of the Foundation

The design of the foundation in studied buildings with damages varies as given in Figure 3. Notice the demarcation between basic information about the building, the specific damage, and the cause of damage. A high frequency with buildings that have a specific design, does not necessarily need to be linked to the damage or the cause of the damage.

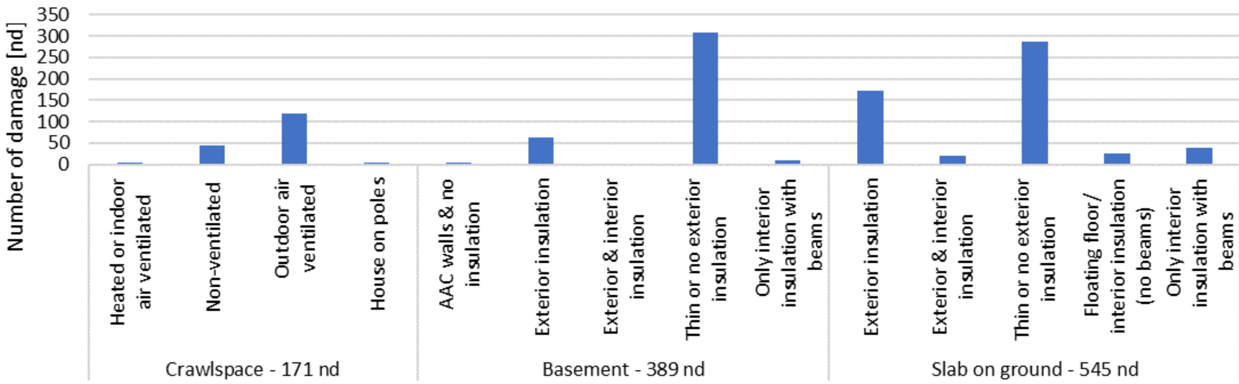

Figure 3. The distribution of damages in buildings with different designs of the foundation.

The results indicate that buildings with only a *Thin or no exterior insulation* under the concrete slab (288 nd) or outside the basement wall (307 nd) is a high-risk design. This design is common in old buildings and is known to be prone to damages. Slab on ground with interior insulation (21 nd + 27 nd + 38 nd) is as also a high-risk design. The limited number of buildings with interior insulation in Figure 3 may depend on that that the design it is already repaired or that private owned single-family houses from the 70s which may be low-priority customers.

The results show that buildings with *Non-ventilated* (44 nd) and *Outdoor air ventilated* (118 nd) crawlspaces are overrepresented with damage in buildings with a crawlspace. The limited number of damages in *Houses on poles* (5 nd) and *Heated or indoor air ventilated* (4 nd) crawlspaces indicate that those designs are unusual or might work rather well.

4.4 Design of the Cladding System – Air Gap Designs and Façade Materials

The distribution of registered damages in buildings with different cladding systems are presented in Figure 4. The dominating façade materials on the outside of the cladding mainly consists of wooden boards (335 nd), clay bricks (360 nd) and rendered façades (319 nd).

A cladding system with *Drainage* is here defined as having a free space with a water discharge ability. A cladding system with *Limited drainage* ability has significant obstacles in the drainage or consists of a water conducting material such as specific mineral wool products. A *No-drainage* cladding has no drainage at all, such as EIFS/ETICS façade systems or has major barriers in its drainage such as brick façades with sealed joints in the bottom. A *High ventilated* cladding system has a free air gap with openings in the top and the bottom. A *Ventilated* cladding system has openings in the top and bottom of the façade but with minor obstacles in the air gap, such as traditional overlapping board on board façades on horizontal battens. A *Limited ventilated* cladding has an air gap but is closed in the top or bottom or has significant horizontal barriers in the air gap. A *No-ventilated* cladding has no ventilation such as EIFS/ETICS façade systems with mineral wool or EPS insulation behind the rendered façade.

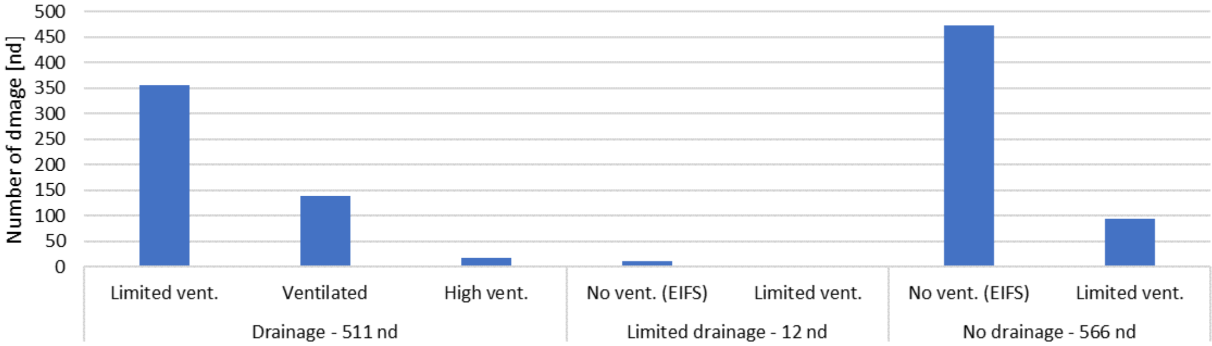

Figure 4. The distribution of damages in buildings with different design of the cladding (16 nd with an unknown cladding were excluded from Figure 4).

Figure 4 shows an example of cross-comparing for the parameters ventilation and drainage capacity. The results in Figure 4 indicates that buildings with *No-drainage* cladding have a high amount of damages. Furthermore, *Drainage* claddings with a *Limited ventilation* also have a high amount of damages. However, notice that the cause of damage not necessary is linked to the cladding design.

4.5 Main Material in the Load Bearing Structure and Different Exterior Wall Designs

The number of damages in buildings with different materials in the load bearing structure and materials in the exterior wall (excluding insulation) are presented in Figure 5.

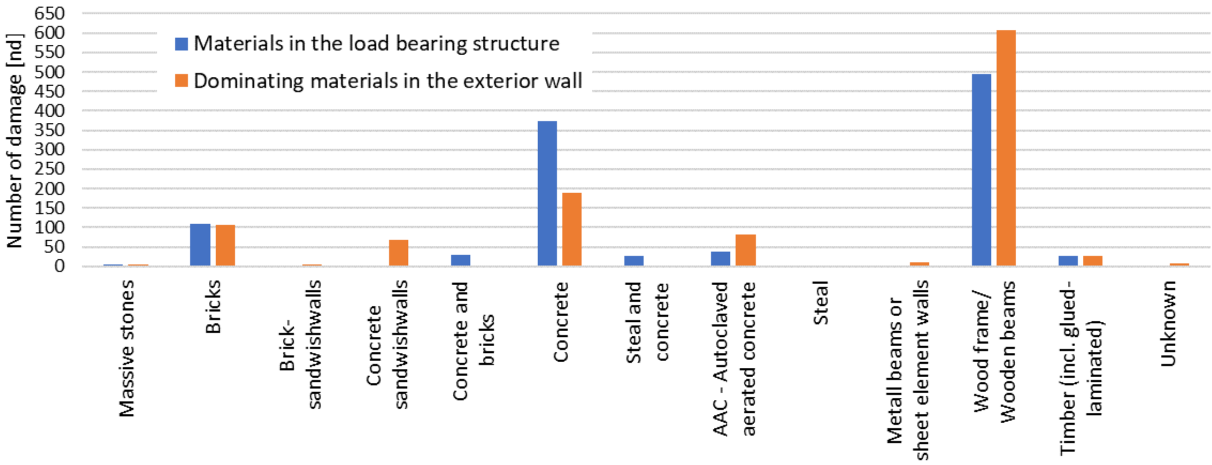

Figure 5. The distribution of damages in buildings with different load bearing structures and wall designs.

It is difficult to draw conclusions from the results in Figure 5 since there is no available information for the number of different built structures and wall designs in Sweden to compare with. The number of damages in buildings with a *Wood frame* or *Wooden beams* compared to

Concrete and other materials must be viewed in relation to the number of built designs. However, the limited number of damages in buildings with nonorganic materials indicates that nonorganic materials are more robust.

4.6 Design of the Roof

The distribution of the number of damages in buildings for different roof designs for ventilation, roof pitch and roof overhang are presented in Table 1.

Table 1. Number of damages in buildings for different roof designs for ventilation, roof pich and roof overhang.

Roof design for air gaps and ventilation	No. of damage	Roof pitch [˚]	No. of damage	Roof overhang [mm]	No. of damage
Non-ventilated compact roof	74	0 - 2˚	227	0 - 50 mm	240
Non-ventilated parallel roof	5	3 - 7˚	422	51 - 200 mm	275
Ventilated air gap/parallel roof	88	8 - 24˚	377	201 - 400 mm	210
Non-ventilated cold attic	19	25 <˚	74	401 - 600 mm	349
Ventilated cold attic	896	Unknown	5	> 600 mm	27
Unknown	23			Unknown	4

The number of damages in buildings with a *Ventilated cold attic* is in line with the claim that ventilated cold attics should be treated as a high-risk construction. The low number of damages in *Non-ventilated parallel roofs* and *Non-ventilated cold attics* indicate that the risk of air leakage from the inside to the attic or the parallel roof may be overestimated or that a higher temperature, caused by a low ventilation, limit the risk of damage. The low number of damages in parallel roofs could indicate that this is a safer design than cold attics. However, since ventilated cold attics are much more common than non-ventilated designs, and there is no available data for the number of different built designs of roof and attics to compare with, it is not possible to draw any proper conclusions without cross-comparing the data to other parameters. Similar circumstances prevail for the parameters *Roof pitch* and *Roof overhang*, where no conclusions could be drawn due to the lack of data for built designs.

5 Discussion

In accordance with Wu et al. (2021) and Mundt-Petersen et al. (2023) the representativeness of the data needs to be processed for further use since the data is not constructed from random samples and dependent on factors such as complexity, the property owners and their ability to pay. This means that the conclusions before the cross-comparing needs to be used cautiously and the results are best viewed as indications. However, compared to other investigations (Boverkt 2018, Health Agency of Sweden 2017) the results are based on damage investigations and not interviews and questionnaires, which enhances the quantifiability. Comparisons to other results were difficult due to different approaches and other studied parameter such as cost and limited information presented within the studies (Josephson and Hammarlund 1999, Love and Josephson 2004, Hwang et al. 2009, Anticimex 2014-2022).

Due to the lack of comparable data and the limited database it is difficult to draw strong conclusions from the results. However, several results will be important in a second step when other parameters concerning the specific damage or cause of damages will be cross-compared, e.g. the location of damage, damaged material and different causes of damages.

6 Conclusions

The most clear and important conclusions are;

- Buildings with thin or no exterior insulation on the outside of the foundations seems to be overrepresented.
- Well-designed indoor-air ventilated or heated crawl spaces and houses on poles seems to work rather well and may not be classified as high-risk designs as opposed to non-ventilated and outdoor air ventilated crawl spaces.
- Buildings without a ventilated air gap or a limited ventilated air gap behind the façade and buildings without a drained function in the cladding are significantly overrepresented in buildings where damages were found.
- The results indicate that there are more damages in condominium association owned multi-family houses compared to public tenancy owned multi-family houses.
- The database needs to be expanded to get more confidence in the results and cross-comparisons can be made to find additional valuable information.

Acknowledgements

This study is a part of the R&D project "Design Guidelines for Moisture Proof Buildings" founded by Akademiska Hus, WoodCenter North, Cementa, The Swedish Federation of Wood and Furniture Industry, Polygon, and Länsförsäkringar. The project was also supported by Derome, NCC, OBOS, RISE and Lindbäcks.

References

Anticimex (2014-2022). *Public reports and statistics for damage or defect building components* https://www.anticimex.se/pressrum/rapporter. In Swedish.

Boverket/ The Swedish National Board of Housing, Building and Planning (2018). *Damages, Failures and Deficiencies in the Building Sector.* Report 2018:36. Boverket, Karlskrona, Sweden. In Swedish.

BKR/ The Swedish Ceramic Tile Council/ Byggkeramikrådet (2021). *BBV – Trade Rules of the Swedish Ceramic Tile Council for Wet Rooms.* 1 ed. Byggkeramikrådet, Stockholm, Sweden.

BYG-ERFA/ The Danish Foundation for Experiences of Building. *Expertice Guidelines.* BYG-ERFA, København, Denmark. https://byg-erfa.dk/erfaringsblade. In Danish.

Byggskadefonden/ The Danish Foundation for Damages in Buildings *Reports of damage in building components.* Byggskadefonden København, Denmark. https://bsf.dk/erfaringer/artikler-om-byggeskader. In Danish.

Health Agency of Sweden (2017). *Report of the Swedish environmental health 2017/ Miljöhälsorapport 2017.* Artikelnr 02096-2016. Folkhälsomyndigheten, Sweden. In Swedish.

Hwang, B. G., Thomas, S. R., Hass, C. T. and Caldas, C. H. (2009). *Measuring the Impact of Rework on Construction Cost Performace.* Journal of Construction Engineering and Management 135(3) p 187-98.

Josephson, P. E. and Hammarlund, Y. (1999). *The causes and costs of defects in construction: A study of seven building projects.* Journal of Automation in Construction**,** 8(6) p 681-87.

Love, P. E. D. and Josephson P. E. (2004). *Role of Error-Recovery Process in Projects*. Journal of Mangagement in engineering 20(2) p 70-79.

Mundt-Petersen, S. O., Wallenten, P., Joelsson A., and Kläth M. (2023 Distribution and location of damages in Swedish buildings. Proceedings 13th Nordic Symposium on Building Physics, June 2023, Aalborg, Denmark.

Safe Water/ Säker Vatten (2021). *Industry Regulations – Safe Water Installation/'säker vatteninstallation' 2021:1.* Säker vatten AB, Stockholm, Sweden.

SBC/ Statistics Sweden (2022). *Number of competed dwellings.*

SWDC - Swedish Water Damage Center/ Vattenskadecentrum (1977-2022). *Yearly public reports of statistics for free water damages.* http://www.vattenskadecentrum.se/rapporter. In Swedish.

Wu, P. Y., Mjörnell, K., Mangold, M., Sandels, C. and Johansson, T. (2021). *A Data-Driven Approach to Assess the Risk of Encountering Hazardous Materials in the Building Stock Based on Environmental Inventories.* Journal of Sustainability 13(14) 7836 DOI: 10.3390/su13147836.