Review

Not peer-reviewed version

Lessons Learned from Different Types of Building Defect Information Sources

Line Berg Oppedal * and Tore Kvande

Posted Date: 21 March 2024

doi: 10.20944/preprints202403.1266.v1

Keywords: Moisture defects; Maintenance; Buildings envelope; Climate adaptation; Database sources

Review

Lessons Learned from Different Types of Building Defect Information Sources

Line Berg Oppedal [1,*] and Tore Kvande [2]

1 Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU); linebop@stud.ntnu.no (L.B.O.)
2 Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU); tore.kvande@ntnu.no (T.K.)
* Correspondence: linebop@stud.ntnu.no

Abstract: Building defects are very prevalent and contribute significantly to a building's economic value. There are numerous information sources on building defects that have a lot potential for learning more about building defects. This study aimed to identify the information sources used in previous building defect studies and to identify the motivation for carrying out such studies. To fulfil this aim a scoping study was carried out. The information sources identified included insurance companies, private databases, questionnaire surveys, lawsuits, building surveys, client complaint forms, and maintenance reports. This study found that insurance company and client complaint forms include the largest collection of real building defect cases, but such databases may lack detailed descriptions of the causes of the defects. The main purposes of building defects studies identified here included design challenges, identification of defects, building maintenance management, quality management, systematization in data collection, providing an overview of typical defects, and classifying defects. Identification was found to be the most common purpose, indicating that the industry wants to learn more. This study identified research gaps in the climate perspective in relation to building defects. Most of the studies focused on the economical perspective, and none focused on the carbon footprint perspective.

Keywords: moisture defects; maintenance; buildings envelope; climate adaptation; database sources

1. Introduction

Building defects not only incur great economic cost, but also contribute to more material extraction and construction emissions and therefore increase the building's carbon footprint. Building defects occur worldwide, and the monetary costs associated with repairing building defects is often used to describe the magnitude of building defects. For example, in residential and industrial buildings in Australia the costs of rework were found to be respectively 3.15% and 2.40% of the buildings value [1]. Another study in Australia indicated that building defects contribute 4% of the total construction costs [2]. In 2004, a study in Denmark showed that reworking building defects cost about 1.6 billion euro, which was 10% of the sector's turnover [3]. According to SINTEF, the cost of repairing building defects in Norway accounts for between 2% and 6% of the annual capital invested in new buildings [4]. Another survey by Norsk takst [5], a professional organization for appraisers in Norway, indicated that this value is much higher, stating that 12% of a building's costs come from the repair of building defects during construction. The variation in financial estimates may indicate that a reliable overview of the extent of building defects is lacking, for example, due to a lack of systematization in the collection of the defect cases.

To reduce costs, time, and emissions related to buildings, building defects need proper attention so that the stakeholders can gain important knowledge about the issue [6]. A better understanding of defect causes will form a base for improving the quality of buildings [7], thus it is important to gather building defect information systematically and to identify patterns and relations [8–10]. Today it is

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

possible to gain insight from a range of different building defect information sources if provided access to them, for example, by using machine learning and artificial intelligence.

For the present study, the building defect definition of Ingvaldsen [4] was primarily used: "A damage or flaw that compromises the quality of the building or building part". Another commonly referred to definition, which is more specific but in line with [4], is given by Watt [11]: "A defect is the term used to define a failing or shortcoming in the function, performance, statutory or user requirements of a building, and might manifest itself within the structure, fabric, services or other facilities of the affected building". Several other definitions of building defects exist. For example, Pedersen et al. [12] limit building defects to "deviation from regulation on technical requirements for construction works". Further, Mundt-Petersen et al. [13] classify defects as follows: *Damage*, "when a material or building component has lost its essential properties", *failure*, "a clear deviation from proper procedures", and *functional defect*, "not fulfilling needed feature requirements". In addition, quality is defined by Arditi & Günaydın [14] as "meeting the legal, aesthetic, and functional requirements of a project".

Kvande and Lisø [15] distinguish three main types of building defects, shown in Figure 1, including defects due to flawed construction (design and execution), due to flawed use, or due to flawed maintenance. Of these, process-induced building defects are caused by faulty design or execution in the as-built building, or faulty repair. Damages that occur because of normal wear are not regarded as building defects by [4,15].

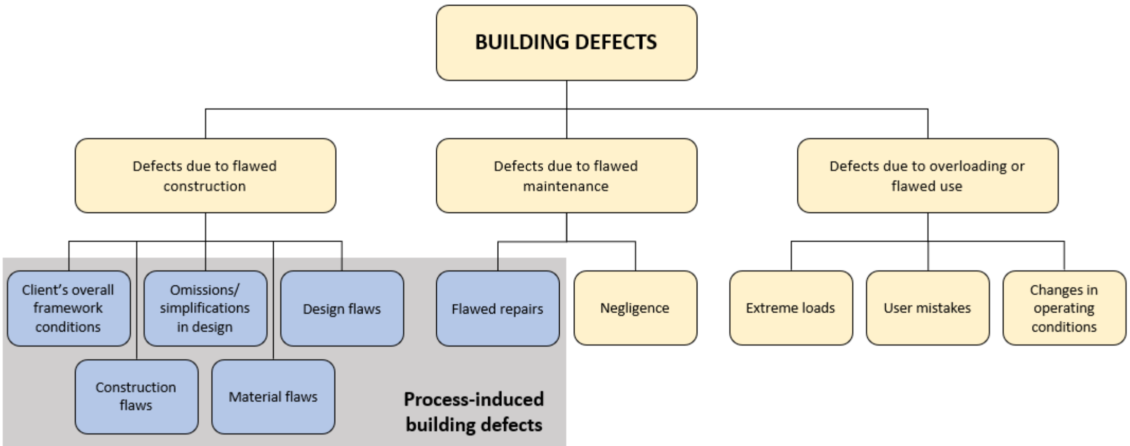

Figure 1. Classification of different types of building defects. Figure is drawn from [15], based on [4].

There seem to be a lot of scientific studies on building defects with a variation of databases, cases, motivation, and solutions on the issue of building defects. The purpose of this paper was to identify currently available types of databases on building defect cases and to gain an understanding of pros and cons and what kind of learning that may be drawn from the different sources. To guide the investigation, the following research questions were asked.

1. What types of information sources are available regarding building defects?
2. What are the main purposes for the scientific studies of building defects?
3. How can the findings from the literature survey be used further?

A literature survey was conducted to answer the research questions. The survey was conducted systematically by using three different library databases and different search strings. The key words for the literature survey were limited to "water" and "moisture" defects because such damages are the most widespread and the most prevalent according to [6]. However, research on other defects was also included to get a broader understanding of the information sources for building defects. While a range of building defect definitions exist, it may be difficult to compare findings from the different surveys because some studies may include flaws or faults that are excluded by others.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

2. Materials and Methods

2.1. Scoping Studies

A scoping study was conducted to obtain an overview of the state of art in the knowledge of building defects. Arksey and O'Malley's [16] approach was used by following the five stages of their framework:

1. Identifying the research questions;
2. Identifying relevant studies;
3. Study selection;
4. Charting the data;
5. Collating, summarizing, and reporting the results.

The overall process for this research is illustrated in Figure 2.

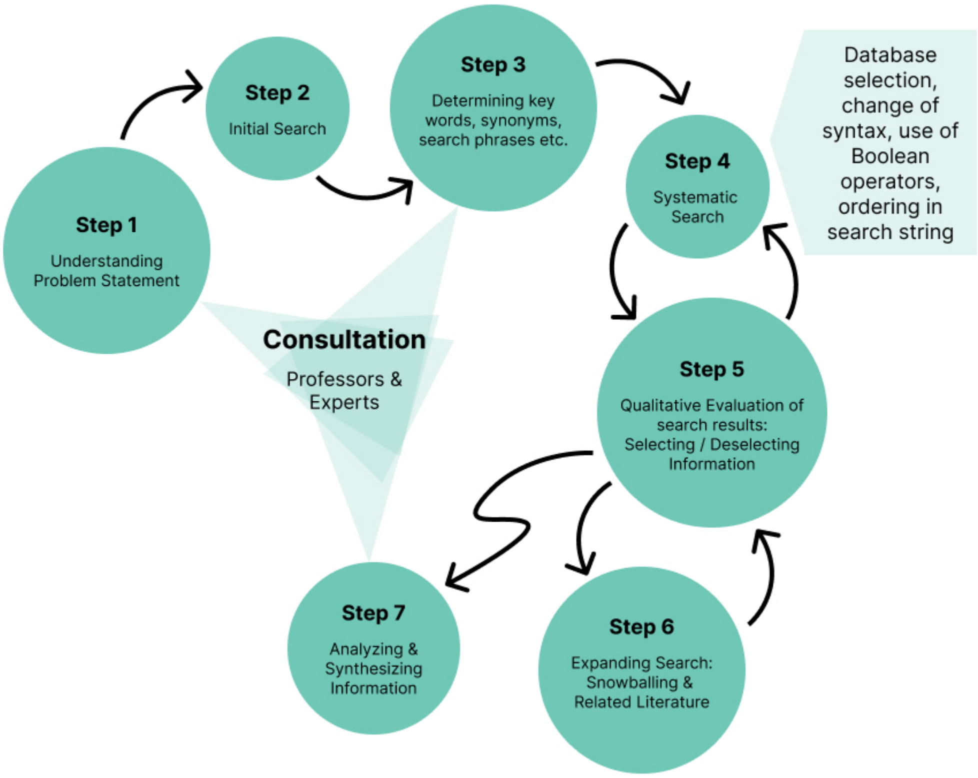

Figure 2. The overall process for the scoping study. Reprinted with permission from Refs. [17,18].

Based on the initial search (Step 2), the following key words (Step 3) of the literature survey were "building defects", "moisture", and "water". Web of Science, Scopus, and ScienceDirect were the databases used for the systematic search (Step 4). The number of documents found by different search strings using these keywords in the databases are shown in Table 1. These are the articles identified after Step 4 in Figure 2.

Table 1. Number of articles per database per search string.

	Number of articles		
Search string	Web of Science	Scopus	ScienceDirect
"Building defects" AND "moisture"	23	21	69
"Building defects" AND "water"	27	23	135

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

The evaluation of the articles (Step 5) was done by assessment of titles and keywords. A total of 70 articles were identified and therefore no further expansion of the search was made (Step 6). The selection process of the articles (Step 7) started with an assessment of the abstract before the full text was viewed. A total of 36 articles were identified as relevant literature. The other 34 articles were excluded for one or more of the reasons below:

- Defect detection methods (e.g. [19])
- Condition survey methods (e.g. [20,21])
- Limited to structural defects (e.g. [22])
- Severity level of defects (e.g. [23])
- Methodology for maintainability assessment (e.g. [24,25])
- Investigation limited to mould (e.g. [26,27])
- Literature research and not case studies (e.g. [28,29])
- Testing the performance of different solutions or building elements (e.g. [30,31])

2.2. Reflexive Thematic Analysis

The type of information source and the main purposes of the articles were categorized using a reflexive thematic analysis. The purpose of this method is to get an overview of the literature and to identify patterns. The reflexive thematic analysis was done following the six steps from [32]:

1. Becoming familiar with the data;
2. Generating initial codes;
3. Searching for themes;
4. Reviewing themes;
5. Defining themes;
6. Writing-up.

The description of the different categories is shown in Tables 2 and 3.

Table 2. Description of categories for the types of information sources.

Category	Description
Insurance company databases	The authors have analysed registers with claims from clients seeking compensation for building defects. The data are normally not publicly available.
Private databases	These databases are owned, controlled, and maintained by an organization for internal use and are not publicly available. The collectors can be developers, contractors, science organizations, or damage investigators. The authors of these articles have gotten permission to access and analyse the cases anonymously.
Questionnaire surveys	The authors have distributed questionnaires to potential respondents for a specific study.
Building surveys	The authors have conducted surveys in the buildings by themselves for a specific study.
Lawsuits	The authors have studied the public descriptions of judgements and analysed the data.
Client complaint forms	The authors have analysed complaints reported by the users/owners and collected by the building owners, developers, or contractors.
Maintenance reports	The authors have analysed data reported by the maintenance teams responsible for the buildings.

Table 3. Description of categories for the main purposes of the building defects studies.

Category	Description
Design challenges	These articles refer to certain constructions or solutions and investigate the challenges to these designs.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

Identification	These articles include the identification of specific elements based on different key issues such as origin, contributing factors, type, risks, relations, and frequency in relation to different periods and types of buildings.
Overview of typical defects	These articles aim to get a general overview on the most common building defects.
Classification	These articles organize defects based on certain properties.
Building maintenance management	These articles focus on gaining information to reduce maintenance costs and to develop strategies to save maintenance expenses.
Quality management	These articles involve implementing principles and methods to ensure and improve the quality of buildings.
Systematization in data collection	These articles look at the importance of systematization to gather data so that the identification or classification is more valid. Other articles also have systematically collected data, but these articles aim to emphasize that this is important to achieve good results.

3. Results

3.1. General Overview of the Literature

A general overview of the 36 scientific articles is given in Table 4. The purposes in bold are the main categorization for the study, and the remaining bullet points are supplementary information about the studies. Of the identified articles, the trend shows that the number of articles per year increased. There were 12 scientific articles published between 2003 and 2013, and 24 between 2014 and 2023. Most attention is given from Malaysia, Norway, and Spain, with 7, 6, and 4 scientific articles, respectively.

Table 4. General overview of the scientific articles.

Type of Information Source	Ref.	Number of defects	Country	Main Purpose of Study	Period (phase)*
Insurance company databases	[8] [9]	27,074	Belgium	• **Systematization in data collection** • Identifying patterns • Enhancing quality	1991-2019 (-)
	[2]	8,128	Australia	• **Quality Management** • Making a framework • Systematization in data collection • Identifying current trends of defects	2011-2018 (-)
Private databases	[33]	175	Norway	• **Identification** of typical defects • Present best-practice solutions • Weather-protective flashings	1963-2001 (-)
	[6]	2,423		• **Overview of typical defects** • Learning from experience	1993-2002 (-)
	[34]	302		• **Design challenges** • Climate adaptation • Masonry structures	1983-2002 (-)
	[35]	465		• **Overview of typical defects** • Norwegian pitched roof defects	1993-2002 (-)
	[36]	150		• **Identification** of typical defects • Performance	1993-2017 (-)

 doi:10.20944/preprints202403.1266.v1

				• ETICS	
	[37]	42,753	Australia	• **Identification** of patterns	2002 (-)
	[38]	Unknown	Australia	• **Quality Management** • Making a framework	-
	[39]	16,701	South Korea	• **Classification** • Risk matrix of residential building defects	2008-2017 (Post-handover)
	[40]	7,554	South Korea	• **Identification** of building defect risks in residential buildings	2008-2017 (-)
	[10]	6,087	South Korea	• **Systematization in data collection** • Classification matrix by defect liability period in residential buildings • Better distribution of defect costs	2008-2017 (Maintenance phase)
	[41]	560	Poland	• **Identification** of typical defect in residential buildings	2018-2020 (Warranty period)
	[13]	1,105	Sweden	• **Identification** of defect type and location	2014-2021 (-)
	[42]	1,055	Malaysia	• **Identification** of common defects and methods to solve them	2009-2019 (-)
Questionnaire surveys	[43]	118	Malaysia	• **Building maintenance management** • Design challenges	-
Questionnaire surveys	[44]	310	Malaysia	• **Quality management** • Identifying defects and causes	-
Questionnaire surveys	[45]	Unknown	Malaysia	• **Identification** of contributing factors	-
Questionnaire surveys	[46]	63	Malaysia	• **Building maintenance management** • Identifying building defects related to maintenance	-
Questionnaire surveys	[47]	Unknown	Malaysia	• **Identification** of defect occurrence	-
Questionnaire surveys	[48]	Unknown	Sweden	• **Identification** of defects from owners' perspectives • Identifying relations between a projects characteristics, the company size, and the defects	-
Questionnaire surveys	[49]	Unknown	Nigeria	• **Building maintenance management** • Investigating the significance of design and construction defects	-
Questionnaire surveys	[50]	Unknown	Ethiopia	• **Building maintenance management** • Assessing the most prevalent building defects • Identifying significant factors, impacts of construction defects and measures	-

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

Building surveys	[51]	6,758	Iraq	• **Identification** of types of defects in newly constructed houses	2009-2012 (Post-Handover)
	[52]	Unknown	Singapore	• **Identification** of sources and risk factors of defects in wet areas of buildings	- (User phase)
	[7]	Unknown		• **Identification** of defects in wet areas • Evaluating design, maintenance, and material	- (User phase)
Lawsuits	[53]	222	Italy	• **Classification** of types of defects • Impact and origin of defects • Evaluating responsibilities of involved technical personnel	2000-2011 (-)
Client complaint forms	[54]	966	Spain	• **Identification** of factors that affect the concurrency of building defects • Investigating differences of the quality for flats and detached houses	- (Post-handover)
	[55]	2,351		• **Identification** of type, source, and origin in newly constructed residential buildings • Finding preventive measures	2004-2013 (Post-handover)
	[56]	2,351		• **Classification** of defects based on type, location, and subcontract in newly constructed residential buildings	2004-2006 (Post-handover)
	[57]	52,552		• **Quality Management** • Investigating whether quality control measures are operating as intended or not • Comparison of construction and post-handover defects • Identifying who identifies defects	2012-2017 (Construction and post-handover)
	[58]	2,047	Norway	• **Identification** of common defects, causes, consequences, and improvement opportunities	- (Handover)
	[59]	55,439	Malaysia	• **Identification** of common defects at residential colleges	- (User phase)
Maintenance reports	[60]	3,209	United Kingdom	• **Identification** of common defects, locations, severity, and responsible personnel in newly constructed houses	- (User phase)
	[61]	2,929	United States	• **Design challenges** • Making a framework • Identifying causes of design-related defects	- (User phase)

* The period of data collection and the phase of the building process where (-) indicates unclear period or phase.

3.2. Type of Information Source

The distribution of information sources used in the articles is given in Figure 3. The articles per category are presented in the following sections.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

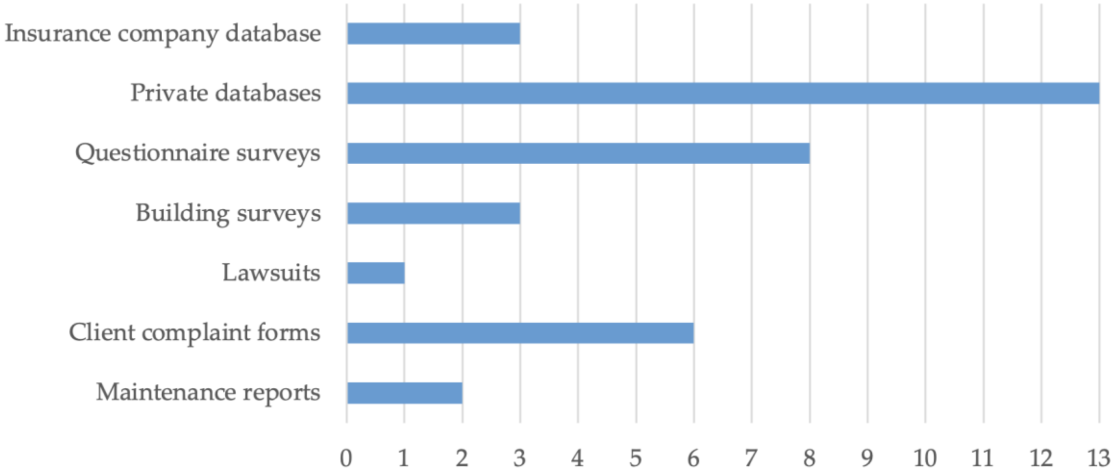

Figure 3. Number of articles per information source.

3.2.1. Insurance Company Database

The papers of De Vos et al. [8] and Van Deen Bossche et al. [9] were based on a collection of building defects cases from 1991 to 2019, provided by the largest Belgian insurance company. The total amount of cases collected was 27,074, which were processed and filed by jurists or engineers. Of these cases, De Vos et al. [8] selected four categories to analyse, which included problems with moisture, stability, cracking, and residential nuisance. These categories included 13,068 of the total number of cases. Van Deen Bossche et al. [9] selected six categories to analyse, which were problems with moisture, stability, neighbour damage, HVAC, acoustics, and energy efficiency. Only 9,918 cases remained because the postal code and building category were required for the study.

A similar study from Australia by Sandanayake et al. [2] used data collected by the Victorian Managed Insurance Authority (VMIA) between 2011 and 2018. The insurance company had gathered a total of 8,128 defects, and this study analysed 3,048 unique claims of the total.

3.2.2. Private Databases

Lisø et al. [33] investigated building defects by analysing 175 assignment reports by the former building research institute Norges byggforskningsinstitutt (NBI) from the period between 1963 and 2001. Later NBI merged with SINTEF and they assembled a substantial building defect archive gathered from investigation cases and field studies from the Norwegian building industry over the last 60 years [62]. Multiple articles have used the SINTEF archive as a database [6,34–36]. Lisø et al. [6] investigated a dataset of 2,423 cases collected from the reports between 1993 and 2002. Gullbrekken et al. [35] performed a more thorough investigation on Norwegian pitched roof defects from the same period (1993 to 2002). A special study on masonry defects was conducted by Kvande & Lisø [34] based on 302 process-induced defect assignments from the archive between 1983 and 2002. Finally, Kvande et al. [36] summarized experiences with External Thermal Insulation Composite Systems (ETICS) made from laboratory experiments as well as defect causes. A total of 6% of the defects in the SINTEF archive were related to ETICS between 1993 and 2002 [6]. A total of 61 buildings had ETICS defects in the period of 1993 to 2017, and 150 causes were identified [36].

In Australia, Ilozor et al. [37] studied the Archicentre’s database for residential building defect inspections. A total of 42,753 houses were inspected, and the defects identified were systematically collected in the Archicentre's database.

Another Australian database, collected by The Victorian Civil and Administrative Tribunal (VCAT), was used by Pamera & Gurmu [38] to select five cases so that the most prevalent defects of these could be analysed further.

In Korea, multiple studies investigated defects from several residential buildings between 2008 and 2017 [10,39,40]. Lee et al. [39] examined 16,701 defect from 133 residential buildings to make a

 doi:10.20944/preprints202403.1266.v1

defect risk profile, while Lee et al. [40] examined 7,554 defects from 48 residential buildings to evaluate the impact of defect risk in the user phase. Lee et al. [10] examined 6,087 defects from 48 residential buildings and classified them into a defect classification matrix based on the defect liability period.

The database of a Polish developer with collected warranty period reports was used by Plebankiewicz & Malara [41] to identify typical defects and their occurrence between 2018 and 2020. A total of 560 defects were found in the warranty period for 432 flats. The authors validated 353 of the cases.

Collected information from four Malaysian specialist waterproofing contractors was used by Talib & Sulieman [42] to analyse building defect cases. The information was based on 1,363 defect cases.

Mundt-Petersen et al. [13] collected building defect data from the private databases of six Swedish accredited damage investigators. A total of 1,105 defects from 265 damage investigation reports were investigated.

3.2.3. Questionnaire Surveys

In Malaysia, there were several studies on building defects based on questionnaire surveys. A literature review was conducted by Islam et al. [43], where 42 design challenges and 11 mitigation measures were identified. The authors distributed 300 questionnaires and collected 118 responses. All the respondents had first-hand experience from the maintenance industry. Almost half of the respondents had more than ten years of experience, and 36% of the respondents were facility managers, 23% were consultants, 22% were building supervisors, 11% were quantity surveyors, and 8% were senior management. The study of Abdul-Rahman et al. [44] had users as respondents, including 310 residents from affordable housing in Malaysia. Ahzahar et al. [45] gathered information for their study by interviewing 12 contractors and 29 consultants and conducting a questionnaire survey. The survey was sent to different actors in the Malaysian construction industry. The study by Jesumoroti et al. [46] used medical officers and nurses as respondents, and 93% of the respondents had work experience and academic backgrounds. A total of 63 defects were reported. The study by Talib & Sulieman [47] had 86 industry actors as respondents.

More experienced Swedish respondents answered the questionnaire survey for the study of Jonsson & Gunnelin [48]. The participants in the survey were board members of cooperative owners, and these respondents together had experience from 1,107 projects. A total of 1,563 surveys was sent out representing 394 residential buildings.

In order to collect the necessary data for analysis, Waziri [49] sent questionnaire surveys to 60 employees who work in the offices of consultants, contractors, and building owners in Nigeria. A total of 47 questionnaires, which was a response rate of 73%, were obtained and analysed. The respondents were in charge of either design, building, or maintenance of residential buildings.

In Ethiopia, main stakeholders such as consultants, contractors, and clients were the respondents of the questionary survey by Awasho & Alemu [50]. The authors used the survey to gather primary data. A total of 49 respondents answered, of which 18 were consultants, 18 were contractors, and 23 were clients. This was a response rate of 84%. The respondents were distributed on nine projects.

3.2.4. Building Surveys

A building survey of 652 newly constructed residential houses in Iraq was investigated by Wali & Ali [51]. The survey was conducted directly after handover, and 6,758 defects was discovered.

In Singapore, Chew [52] studied 56 high-rise non-residential buildings that were randomly selected by conducting a building survey and interviewing the property managers.

Another study in Singapore by Chew & De Silva [7] studied cases from 67 high-rise residential buildings, ranging in age from 1 to 35 years old, using data received from site visits and accumulated reports. The reports were gathered from diverse actors in the industry such as maintenance managers, building diagnostic specialists, councils, etc.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

3.2.5. Lawsuits

Sassu & De Falco [53] investigated lawsuits from the archives of district court judgments between 2000 to 2011 in Italy and classified the described defects. The court appointed an engineer to conduct an interim technical assessment on the cases to determine the causes and origin of the defects.

3.2.6. Client Complaint Forms

In Spain, there were several studies on building defects using client complain forms as the dataset [54–57]. Forcada et al. [54] investigated handovers from 95 residential buildings and looked into the quality of flats and detached houses as reported by the occupants. Forcada et al. [55] and Forcada et al. [56] based their study on the database of four Spanish builders. The builders had collected data based on client complaint forms from post-handover, including 2,351 defects from seven buildings. Forcada et al. [56] focused on the most common defects, and Forcada et al. [55] focused on the causes. By analysing the client complaint forms of 2,179 flats, a total of 52,552 defects were identified in the study of Forcada et al. [57].

Another post-handover study from Norway by Shirkavand et al. [58] assessed the most common building defects based on seven projects. In addition, the authors conducted nine interviews with employers from both client and contractor organizations. Of these, one was a construction manager, four were project managers, two were project developers, one was a design manager, and one was an energy consultant. All of them had a key role in the building projects. The seven projects had a total of 1,549 building defects, 315 electrical defects, and 183 technical defects.

The client complaint forms from nine residential colleges in Malaysia were used as the dataset in the study of Dzulkifli et al. [59]. The forms collected were from the period 2012–2017. The study investigated 55,439 cases from 179 buildings.

3.2.7. Maintenance Reports

Pan & Thomas [60] studied 3,209 defects in 327 newly built homes that were built according to the building regulation and the Code for Sustainable Homes in the United Kingdom. The dataset of the study was based on maintenance reports.

By conducting a nine month survey of 74 buildings, Chong & Low [61] investigated latent building defects in the United States. The dataset of this study was mainly based on maintenance reports from the property managers. In addition, interviews and building surveys were conducted to verify the information from the reports.

3.3. Main Purpose and Findings for the Studies

The categorization of the main purpose of the articles are given in Figure 4.

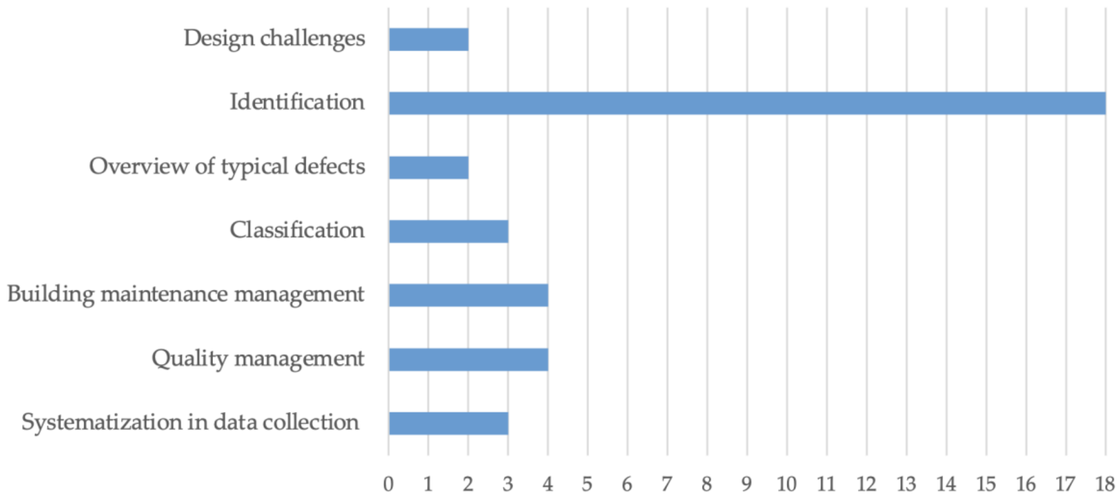

Figure 4. Number of articles per main purpose.

3.3.1. Design Challenges

Kvande & Lisø [34] had the main purpose of presenting design challenges related to masonry structures. The investigation of 302 masonry defects found restrained shrinkage and thermal movement to be the most frequent defect category. In addition, driving rain and frost action were found to be the most considered climatic challenges in maintaining high-performance masonry structures. Many of the crucial and often unrecoverable defects were found to be the result of minor errors or mistakes and could have been avoided with more detailed engineering.

Chong & Low [61] investigated design challenges and methods to prevent typical latent building defects. The survey of 74 buildings and systematic data collection showed that the main causes of design-related failures were impacts from weather and occupants and defects related to wet areas.

3.3.2. Identification

The main purpose for Kvande et al. [36] was to identify the variables that affect the performance of ETICS with rendering. The study discovered that ETICS are vulnerable to intense driving rain and that the two-stage tightening approach is a more reliable option than ETICS in those locations. One of the most frequent causes of the ETICS defects identified was incorrect assembly of the ETICS components.

Shirkavand et al. [58] had the main purpose of identifying the most frequent building defects at handover in order to improve planning such that defects are reduced. In addition, the authors investigated the causes of the defects, improvement opportunities, and the consequences for the involved parties. Surface damage was the most common defect, but this type of defect is easily fixed at low cost. The second most common defect was missing items and inappropriate installation. Technical installation faults were found to be the costliest flaws and were brought on by poor design. It was found that construction-related defects occurred in the last phase before handover and were the result of human errors, such as falling tools, due to time pressure caused by poor management. The consequences identified were economic losses, productivity losses, and delays.

To identify the most common defects, Dzulkifli et al. [59] investigated client complaint forms. The main finding was that 62% of the complaints were civil defects, e.g. defects in ironmongery elements, plumbing system issues, flooring issues, ceiling issues, or animal attacks on building components. A total of 60% of these were damaged components, 14% were leakages, and 13% were clogs. In addition, electrical defects represented 35% of the defects and mechanical defects were 3% of the total.

Talib & Sulieman [47] also had the main purpose of identifying the most common defects. The study found that the origins of 99% of building defects were related to water seepage problems and that watertightness is therefore very important to keep in mind. The article was not clear on what type of water seepage occurred.

Identification of common building defects and finding methods to solve them was the main purpose of Talib & Sulieman [42]. A total of 18 building defects were identified. It was found that gutters and downspouts had the most defects and that under sizing was the most common cause. The authors pointed out that optimizing the maintenance and operation functions could decrease the number of defects.

Identification of defect types was the main purpose of Mundt-Petersen et al. [13], but the study also looked at their location. The main findings of the study were that 81% of the defects were caused by moisture and that most of the defects were mould growth. In addition, 70% of the defects were on-going and 20% were latent. The article was not clear on the origin of the moisture. It was also found that 28% of the defects were located in the exterior wall and that wooden materials were the most damaged material with 40% of the cases.

A rather narrow study by Lisø et al. [33] had the main purpose of identifying typical defects that are associated with weather-protective flashing and providing best-practice solutions. It was found that 41% of the defects were related to windowsill/weatherboard flashings and 27% were related to parapet flashing.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

A wider study by Pan & Thomas [60] had the main purpose of identifying building defects of new homes built according to the 'Code for Sustainable Homes'. The authors studied the type of defect, frequency, location, severity, and the ones responsible. The study found that the mean average of defects per home was 9.8. The building defect category "making good or adjustments to the finished dwelling" contributed with 709 defects, which was 22% of the total number of defects. Secondly, "malfunctions" contributed with 386 defects, which was 12% of the total number of defects. Kitchens and bathrooms were identified as the locations with the most defects. Plumbers (23%), painters/decorators (19%), and electricians (11%) were identified to be the trades out of 14 categories that most often had to do the rectification work that was reported.

Wali & Ali [51] also had the main purpose of identifying the types of building defects in newly constructed residential houses. An investigation of 652 houses revealed 6,758 building defects, which was a mean of 10 building defects per house and thus was in line with the findings of Pan & Thomas [60]. The study identified 25 different types of defects and that gaps between doors/windows and walls were the most common defects (76%). This study also found that 48% of the defects were finish work, 42% were in doors and windows, 5% were electrical work, 3% were plumbing, and 2% were site work.

Jonsson & Gunnelin [48] looked at residential buildings from an owner's perspective, with the main purpose of identifying building defects in newly constructed buildings. In addition, the authors investigated the relation between the defects and the project's characteristics and company size. This paper found that the most common defects were related to the building envelope and that newly constructed buildings tend to have problems with HVAC systems. A total of 26% of the severe defects were related to leakage from rainwater, 19% were related to the heating system, and 18% were related to the ventilation system. The authors also found that the number of defects increased in big cities, and this could be because of the high demand due to population growth and that quality is therefore not a priority. In addition, it was found that big projects had an increased severity of defects and that medium-sized companies, with 50–250 employees, had the highest number of defects reported.

Chew & De Silva [7] limited their study to identifying defects in wet areas of high-rise residential buildings. In addition, they evaluated the significance of design, construction, maintenance, and materials. It was found that 36% of the defects were water leakage, 27% were paint defects, 10% were service pipe defects, 8% were spalling/cracking, 7% were fungi/algae, 4% were mastic failure, 4% were water ponding, 2% were tile staining, and 1% were cracking tiles. Of these, at least 57% were related to moisture or water. The authors found that the main causes of the defects were related to poor workmanship, inadequate detailing in design, poor design for air movement, ad-hoc maintenance procedures, and unsatisfying material performance. The authors stressed that design, construction maintenance, and materials need adequate attention to improve the quality of buildings.

The main purpose of Plebankiewicz & Malara [41] was to identify the building defects occurring in the warranty period of residential buildings. They found that only half of the reported defects were valid and that the number of valid defects increased over time. It was also found that in the first three months defects related to electrical installation were the most common and the number of these defects decreased over time. However, there were few reports of flaws in windows, door joinery, balconies, terraces, moisture issues, of scuffs on walls throughout the first six months before the frequency of such defects increased.

The main purpose of Chew's [52] study was to identify the sources of building defects and important risk factors that affect the maintainability level of wet areas in buildings. The study investigated the consequences of maintainability for watertightness, spatial integrity, ventilation, materials, and plumbing on the 14 most common defects in wet areas of buildings. It was found that 53% of the defects were related to water leakages, 50% were related to corrosion of pipes, and 47% were related to spalling of concrete.

A risk matrix was used by Lee et al. [40] to identify risks related to building defects. They found that defects in reinforced concrete, finishing, and mechanical/electrical/plumbing work gave the largest economic losses. The costs related to reinforced concrete were mainly caused by broken items and water problems. The causes in finish work were mainly related to broken items, detachment,

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

incorrect installation, missing pieces, and surface appearance. Mechanical/electrical/plumbing work costs were mostly caused by affected functionality and incorrect installation.

Ahzahar et al. [45] identified the factors that contribute the most to defects so that time and costs can be reduced. This study identified poor quality of materials and faults in the construction phase to be the two most common factors contributing to building defects.

The main purpose of Forcada et al. [54] was to identify factors that affect the occurrence of building defects in the post-handover stage and to determine if there is a significant difference of the quality between flats and detached houses. The authors discovered that customers in flats reported more defects than those in detached houses, indicating that the developers had more focus on quality when constructing detached houses. The study also found that the customers mostly complained about visible defects and were not aware of the quality of nonvisible structural elements. Customers' dissatisfaction with the contractor's quality standards was the main cause of their complaints. The authors pointed out that the clients have little influence over the standards of their homes and that increased client involvement might result in fewer complaints.

The main purpose for the study by Forcada et al. [55] was to identify the type and origin of building defects so that measures to prevent them can be found. The main findings of the study were that 64% of the defects were poor workmanship due to building mistakes and omissions. In addition, material quality contributed with 19% of the defects and lack of protection contributed with 16%. The two most common causes were in line with the findings of Ahzahar et al. [45]. The authors pointed that these findings may help enhance quality control because they highlight problems that require proper attention.

The main purpose of Ilozor et al. [37] was to identify whether there is a pattern or sequence in the relations between typical building defects. It was found that proper installation of house foundations and proper execution of house framing may reduce the occurrence of various defect types.

3.3.3. Overview of Typical Defects

The main purpose for the study by Gullbrekken et al. [35] was to get an overview of typical building defects in pitched wooden roofs. It was found that deficiencies in the design, materials, or workmanship accounted for more than half of the defects by allowing precipitation or indoor moisture to enter the building envelope.

The main purpose for Lisø et al. [6] was to get an overview of the typical process behind different defects. This paper found that 66% of the cases were related to the building envelope and that moisture-related defects represented 76% of the 2,423 cases registered, while 22% of the cases were located on the roof. The authors also found that numerous defects were recurrent, which indicated that the building industry does not learn from mistakes and that there is insufficient knowledge exchange.

3.3.4. Classification

Forcada et al. [56] classified building defects based on type, location, and subcontract. Of the 2,351 defects investigated, the most common defects identified were missing items or tasks (37%) and surface appearance (20%). The study found that most of the defects were located in wet areas of the buildings. In addition, the paper found that 38% of the defects arose in door and window subcontracts, 24% in painting subcontracts, and 14% in services subcontracts.

The main purpose for the study of Sassu & De Falco [53] was to analyse building defects by classification of the different types of defects. The paper focused on the origins and consequences of building defects, especially water damage. The participating technical staff's obligations were also evaluated. A total of 36% of the building defects were found to be the result of poor design at the planning stage, whereas 43% of the cases were the result of execution mistakes. In fact, mistakes in both design and execution commonly happened together. The study did a comparison of the distribution of the error causes from 1990 to 1999 and from 2000 to 2011. It was found that the share

 doi:10.20944/preprints202403.1266.v1

of errors in design or during inspection works increased from 24% to 36%, constructive defects were rather stable at 45% and 43%, and lack of or defects in maintenance decreased from 32% to 21%.

Classification of different building defects into a defect risk matrix was the main purpose of Lee et al. [39]. The classification was based on the type of defect and work and the defect's location. The study found that incorrect installation and missing tasks were the most severe defects.

3.3.5. Building Maintenance Management

Jesumoroti et al. [46] investigated building defects in relation to maintenance management in hospitals so that defects can be prevented. The main findings were related to cracked floors, floor tile failures, wall tile failures, clogged toilets, and damaged windows. These defects were a result of inadequate maintenance planning, which was made worse by subpar design and construction. The defects led to aesthetic problems as well as functional problems for the hospitals.

Another study by Awasho & Alemu [50] evaluated building maintenance procedures and building defects in Mettu building projects in Ethiopia. The study found that the top three effects of building defects were project delays, high maintenance costs, and reputational damage. In addition, it was found that the best ways to reduce the building defects were proper and routine maintenance and periodic construction supervision. The respondents ranked tight budgets, lack of building maintenance guidelines, and cultural aspects as having the greatest impact on the maintenance management.

In Maiduguri, Nigeria, Waziri's [49] main purpose was to determine the impact that building defects had on building maintenance. The study found that the factors with significant impact on maintenance are poor materials, lack of supervision and quality control, and lack of compliance with specifications.

Islam et al. [43] investigated the impacts that building defects brought on by design flaws have on maintenance costs as well as strategies to save maintenance expenses. The literature survey identified 42 design challenges and 11 mitigation measures. These were sent to respondents in the maintenance industry so that the respondents could grade the design challenges and measures in terms of how they might increase maintenance costs. It was found that maintenance costs increased mostly in relation to architectural design challenges.

3.3.6. Quality Management

The main purpose for the study by Sandanayake et al. [2] was to develop a methodological framework to improve quality management in buildings. The study systematically collected data and used the dataset to analyse patterns on building defects and to identify the current trends in building defects. It was found that poor workmanship caused 85% of the total defects. Of these, 42% were attributed to structural defects. In addition, the study found that waterproofing defects had the highest cost. The paper resulted in a framework including control and enforcement, innovation and technology use, the promotion of best practices, and the auditing of inspections. The author suggested that this framework can be used to minimize the occurrence of common defects.

Another study by Pamera & Gurmu [38] also sought to develop a framework to improve building quality. This study proposed the Defects Identification and Analysis Framework. The framework was based on the causes of the defects and the technologies used to identify the defects. The purpose of the framework is to reduce the frequency of the defects by using adequate measures. Some of the most common defects identified were installation errors in pipes, water damage, plumbing defects, internal water leakage, and wall cracking.

Abdul-Rahman et al. [44] found that the most common defects were leaking pipes, total failure of water supply systems, cracking in concrete walls, faulty doorknobs, and concrete wall dampness. According to the study, subpar materials, subpar workmanship, and inadequate routines for inspection and monitoring can all be contributing factors to the faults. The study suggested that the quality of the finished building might be increased by involving more client-oriented monitoring and supervision on site.

The main purpose of Forcada et al. [57] was to study if implemented quality control measures adequately carry out their functions. To address the issue, the authors compared the defects identified by the customers with the remaining defects at handover. This could give a better understanding of the nature of defects, who identifies them, and when the defects are resolved so that the quality management can be improved. The study investigated the frequency, distribution, and influence of the defects. The most common defects found in this study were surface appearance defects, which accounted for 65% of the total defects.

3.3.7. Systematization in Data Collection

Finding patterns by systematically collecting data was the main purpose of De Vos et al. [8], who used the collected data from an insurance company to analyse the different types of defects and their frequency in relation to the construction time by systematically mapping the defects. The analysis found that 49% of all technical defects were moisture problems, and the roof (25%) and basement (21%) were the common locations for problems to occur. A total of 19% of the defects were stability problems, 17% were cracking, and 16% were residential nuisances. The paper also discusses the temporal evolution of claim distribution and the points in the building process at which claims were made. It was found that the number of claims increased from 1991 to 2019. It was also found that 47% of the defects occurred prior to provisional acceptance (PA), 13% between the PA and the final acceptance (FA), 28% within 5 years after FA, and 12% between 5 and 10 years after FA. In contrast to stability issues, which mainly occurred prior to FA, moisture problems, cracking, and residential nuisances occurred within 5 years after FA.

The study of Van Den Bossche et al. [9] was a follow-up study of [8], focusing on the geographical variability of building defects. The authors aimed to identify external factors that contribute to building defects. The new knowledge that was acquired might contribute to improved quality control and prevention of defects. The study found that wind speed and the number of walls the building shared with its neighbours had the greatest effect on the number of building defects. The authors concluded that demographic, geographic, and climate factors did not have a significant impact on the occurrence of the defects.

Lee et al. [10] systematically collected data to classify the defects into a classification matrix based on the defect liability period. The study aimed to give a better distribution of the defect costs among the involved parties and to identify the frequency of the defects by using this matrix. It was found that the highest frequency of defects was in the structural and finish work and that defects and water problems in reinforced concrete were the most serious defects.

4. Discussion

4.1. Type of Information Source

The identification of the various information sources for scientific research offers several lessons. Chong & Low [61] stated: “It is impossible to identify all types of latent defects without a good information source to rely upon.” From the literature survey, seven types of information sources were identified. The different types are based on different numbers of building defect cases, which influences the validity of the findings. Table 5 shows the variation per category of information source.

Table 5. Defects per category.

Type of information source	Number of articles	Min. number of defects	Max. number of defects	Total number of defects
Insurance company databases	3	8,128	13,068	31,114
Private databases	13	150	42,753	81,288
Questionnaire surveys	8	63	310	491
Building surveys	3	6,758	6,758	6,758
Lawsuits	1	222	222	222

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

Client complaint forms	6	966	55,439	115,706
Maintenance reports	2	2,929	3,209	6,138

The studies based on databases owned by insurance companies had between 8,128 and 13,068 defects. Due to their large number of defect cases and systematic data collection, such information sources might be well suited for ranking typically occurring defects. From a conceptual/theoretical standpoint, these studies advance our understanding of defects and provide a more realistic perspective of defects. On the other hand, the use of insurance company databases has several biases. De Vos et al. [8] point out that there is a possibility of incorrect diagnoses of the defects because some of the cases are processed by lawyers, who do not necessarily have the proper knowledge. In addition, the company may make an unconscious selection of information due to their focus on specific criteria during inspections and assessments, and they might not necessarily investigate the cause of the defect. Both De Vos et al. [8] and Van Deen Bossche et al. [9] point out that because insurance companies are only involved in the defect cases when the professional liability insurance of architects and contractors is activated, the analysis only contains more complex cases and does not cover the population of the different cases. Van Deen Bossche et al. [9] also point out that current insurance companies only have a certain market share, which is often related to a specific geographical area.

The private databases had a varying number of cases, from 150 to 42,753 cases. This means that the credibility varies from database to database and that each source must be evaluated individually based on the quantity of cases and organization. Only a few of the articles addressed the biases of using private databases. The private databases have similar biases as the insurance company such as the competence of those who have conducted the analysis not always being clear, the impact of the geographical location of the collector [6], and the fact that only large-scale defects are included [34,36]. Plebankiewicz & Malara [41] stated that the results could not be generalized because of the small amount of data, but that they did give an indication of typical building defects in general. The authors that used the SINTEF archive discussed biases more thoroughly than other authors. The SINTEF's archive is an example of a database that has experts in the respective field of the specific defect case as data collectors. This expertise, in addition to the large number of defect cases over a long period of time, makes the SINTEF archive a valuable database for understanding the causes of the defects [34].

Questionnaire surveys are a very common method to gather data on building defects. However, the questionnaire surveys often include only a small number of defects because the authors do not provide the information about the number of cases, probably because they do not know how many defects the respondents base their information on. This type of information source therefore relies on the accuracy of the respondents' answers. Jonsson & Gunnelin [48] point out that the way the respondents interpret the questions could be a potential bias. In addition, there is clearly a bias in that the proficiency level of the respondents is unclear even though relevant respondents are used.

Only one article based on building surveys mentioned how many building defects they based their study on, which was 6,758 cases. The number of cases will vary depending on how many buildings are investigated. The biases in these types of information sources are not discussed in the article. The survey of a few selected buildings gives a narrow perspective on the issue of building defects and does not address all possible defects.

The lawsuits also had a low number of defects to base a study on. This could be because many of the defect cases do not become lawsuits but are resolved between the parties. According to Sassu & De Falco [53], assessments from lawsuits are unbiased and are made by an expert and therefore are valuable sources of information for understanding the causes of building defects. The authors do not discuss any bias of this method. A benefit with lawsuits as an information source is that fault is assigned by the court. None of the other sources are clear on the responsibility for the building defects, if responsibility is even investigated at all.

The variation of cases ranged from 966 to 55,439 in the articles based on client complaint forms. These types of information sources contain data concerning the buyer's observations and are

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 March 2024 doi:10.20944/preprints202403.1266.v1

therefore more of an expression of the observer's ability than a description of the actual condition of the building. Forcada et al. [54] point out that buyers are more likely to complain about visible defects and not more complex defects such as structural defects.

The articles that based their study on maintenance reports had around 3,000 cases in their dataset. According to Chong & Low [61], the use of maintenance reports is an efficient way of collecting data on building defects because the owners already collect such data. Therefore, use of these registers can prevent latent building defects in a time and cost-efficient way. The bias of the variation in proper records is also mentioned by the writers, and this could lead to less thorough information about the defect.

4.2. Main Purpose

Eight main purposes were identified from the 36 scientific articles covered by the present survey. To some extent the purposes seem to vary according to the national origin of the study. They might also vary according to the information sources available for the study. The distribution of purposes of the building defect surveys according to national origin is illustrated in Figure 5. None of the surveys aimed to cover the situation in more than one country.

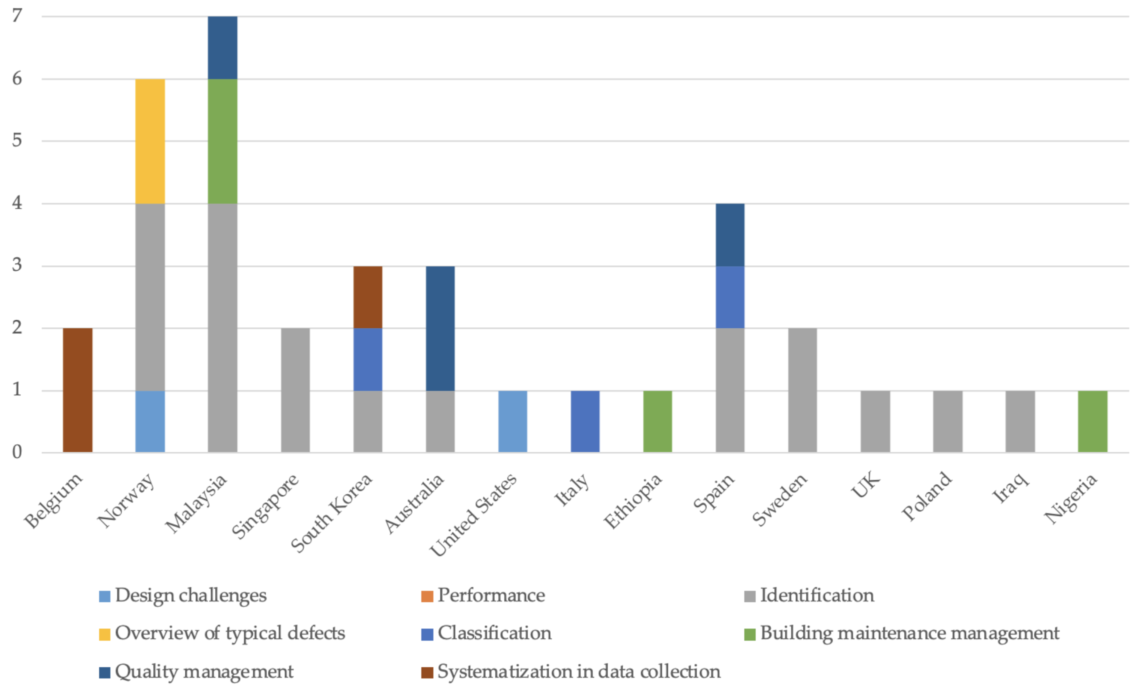

Figure 5. Main purposes per country.

According to Figure 5, there were studies from several countries that aimed to identify the most common defects, which reflects the national industry's interest in gaining more knowledge about building defects. The studies investigated different areas of buildings, different periods of the building's lifetime, and different perspectives, such as the owner's perspective. Some of the national studies focused on classification and systematic data collection, which shows that the authors were interested in systemizing the defects to get a better understanding of the defects. In Norway there has been a focus on identification and on getting an overview of typical defects and design challenges. The Norwegian focus is motivated by an interest in not only identifying issues, but also in solving issues by improving the fault solutions. A harsh climate, which puts extra demand on the building envelope, is an obvious driver behind the Norwegian focus. The Norwegians do not seem to be concerned with management, which may mean that there is not an issue in this regard. Although lacking an in-depth analysis of causes, there were several studies from other countries focusing on quality and building maintenance management, especially from Malaysia. These studies were motivated by improving management, such as processes, frameworks, and procedures, aiming for better building quality and reduced cost.

The present study revealed a variation in the building defect definition and the categorization used by the different studies. The purpose of the individual studies is likely to determine which building defect definition is relevant for the specific study; however, not every publication discusses the definition used. For instance, there were articles that included damage due to normal wear as building defects, e.g. [42,46,61], some did not include normal wear, e.g. [53] and [9], and some articles were not clear on which defects they included. Of the articles identified in the present survey, there were 15 articles that did not define building defects at all. The absence of information about the building defects covered by the study indicate a lack of agreement on what constitutes a building defect. Even among the articles that did not use a specific definition of building defects, 7 of the 15 articles classified the defects based on type, location, or significance. The definition of building defects by Watt [11] was the most commonly used. This definition is much like the definition by Ingvaldsen [4], but Ingvaldsen relates the defects to the quality of the building. Three of the articles used Ingvaldsen's definition. Individual definitions were used by [63–68]. The span in building defect definition used for identifying the relevant faults and flaws in the studies covered by the present survey may vary to such a degree that comparisons of the results are difficult.

4.3. Further Use of the Literature Findings

Obtaining an overview of existing information sources of building defects and the main purposes for studies based on the different sources may be of significance in gaining knowledge about the causes of building defects and effective measures to prevent them. The overview of the types of information sources can identify valuable datasets that have untapped potential. It can also show the importance of collaboration between different actors within the construction industry and that they can learn from each other. Collaboration between developers, contractors, insurance companies, the judicial system, maintainers, and occupants can give the entire industry valuable insights and motivation for jointly improving on imperfect and costly solutions. De Vos et al. [8], Van Den Bossche et al. [9], and Sandanayake et al. [2] showed the potential for utilising insurance company databases from Belgium and Australia to pinpoint focus area for improvement. However, competition between insurance companies is a key reason why such studies are not carried out elsewhere.

Knowing the main purpose of studies helps to understand the context and motivations behind the research, which gives insight into the priorities and concerns of researchers and practitioners. In addition, the diversity of published scientific studies may indicate a variation in the view on building defects. The majority of the articles were motivated by reducing expenses related to building defects, such as construction or maintenance costs, and none of the articles were motivated by the climate perspective of building defects. This shows a research gap on climate impact that the building defects represent. This area of research has a lot of undiscovered potential as the climate perspective gains more and more importance in the industry.

In Norway, Lisø et al. [69] have observed that climate change can lead to significant local differences in climatic exposure, which make robust solutions more important in order to avoid the occurrence of building defects. In Belgium, on the other hand, Van den Bossche et al. [9] reported limited variation in climate, which may stem from small climatic differences within the country. To prepare for the upcoming challenges that Norway will face, Lisø et al. [70] proposed a framework for climate adaptation of buildings in accordance with the Norwegian Planning and Building Act. The framework is motivated by a sorting of building solutions and materials according to the local climatic load, which has been possible as a result of the SINTEF building defect archive. Utilization of other information sources for building defects may expand the library of climate-adapted solutions.

5. Conclusions

The study of building defects is important in order to improve quality and sustainability in the construction industry. This literature survey found 36 scientific studies on building defects with various information sources, including insurance companies, private databases, surveys, lawsuits, client complaint forms, and maintenance reports. The most common information sources used was found to be private databases with 13 articles, questionnaire surveys with 8 articles, and client complaint forms with 6 articles. None of the articles included more than one information source. The credibility of the findings varies depending on the different extent of the datasets, which vary from 63 to 55,439 cases, and varying levels of knowledge among the data collectors. Datasets of insurance companies and client complaint forms can be considered more significant due to their wide number of cases collected, but there are several biases with the information sources that need to be taken into consideration such as the unconscious selection of included information, the competence and thoroughness of the observer, the inclusion of only more complex defects, and a focus on specific geographical areas.

The main purposes of studying building defects identified in this paper include the identification of defects, providing an overview of typical defects, classifying defects, systematic data collection, and gaining a better understanding of building performance, design challenges, building quality, and building maintenance management. Most countries have articles on the identification of defects, which shows that the industry is motivated to learn about building defects. The majority of the studies seek to prevent building defects due to economic savings. Malaysia, Norway, and Spain were found to be the countries with most scientific articles published. It was also found that the building defect definitions used in the studies are different or not clear at all, indicating a lack of coordination in the industry and thus making it difficult to compare the results of various studies.

The novelty of this paper is the discovery of untapped potential in valuable information sources, such as insurance companies, and the identification of research gaps on the climate issue. Further work in this field should focus on utilizing the full learning potential of the different information sources and should focus more on the potential impact of global warming of building defects.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Author Contributions: Conceptualization, L.B.O. and T.K.; methodology, L.B.O. and T.K.; formal analysis, L.B.O.; investigation, L.B.O.; writing—original draft preparation, L.B.O.; writing—review and editing, L.B.O. and T.K.; supervision, T.K. Both authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Literature survey data is available in the spreadsheet attached as Supplementary Materials to this article.

Acknowledgments: The authors acknowledge the collaboration with the project *Norgeshus–Verktøykasse for klimatilpasning av boliger* (the Research Council of Norway grant number 309400).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Love, P.E.D.; Li, H. Quantifying the Causes and Costs of Rework in Construction. *Constr. Manag. Econ.* **2000**, *18*, 479–490, doi:10.1080/014461900500248 97.
2. Sandanayake, M.; Yang, W.; Chhibba, N.; Vrcelj, Z. Residential Building Defects Investigation and Mitigation – a Comparative Review in Victoria, Australia, for Understanding the Way Forward. *Eng. Constr. Archit. Manag.* **2021**, *29*, 3689–3711, doi:10.1108/ECAM-03-2021-0232.
3. Nielsen, J.; Hansen, M.H. *Svigt i Byggeriet. Økonomiske Konsekvenser Og Muligheder for En Reduktion*; Erhvervs- og Byggestyrelsen: Copenhagen, Denmark, 2004;
4. Ingvaldsen, T. *Byggskadeomfanget i Norge. Prosjektrapport 163.*; Norges byggforskningsinstitutt: Oslo, Norway, 1994;
5. Norsk takst. *Norges TakseringsForbund Tar Tempen På Norske Bygg*, 2007.

6. Lisø, K.R.; Kvande, T.; Thue, J.V. Learning from Experience - An Analysis of Process Induced Building Defects in Norway. In *Research in Building Physics and Building Engineering*; Taylor & Francis Group: London, United Kingdom, 2006; pp. 425–432, ISBN 978-0-415-41675-7.
7. Chew, M.Y.L.; De silva, N. Maintainability Problems of Wet Areas in High-Rise Residential Buildings. *Build. Res. Inf.* **2003**, *31*, 60–69.
8. De Vos, J.; Blommaert, A.; Van Den Bossche, N. Statistical Analysis on Belgian Building Defects. In Proceedings of the Current topics and trends on durability of building materials and components, Barcelona, Spain, 20 October 2020.
9. Van Den Bossche, N.; Blommaert, A.; Daniotti, B. The Impact of Demographical, Geographical and Climatological Factors on Building Defects in Belgium. *Int. J. Build. Pathol. Adapt.* **2022**, *41*, doi:10.1108/IJBPA-11-2021-0157.
10. Lee, S.; Lee, J.; Ahn, Y. LDA-Based Model for Assessing the Defect Liability System in Residential Buildings' Maintenance Phase. *J. Perform. Constr. Facil.* **2020**, *34*, doi:10.1061/(ASCE)CF.1943-5509.0001404.
11. Watt, D.S. *Building Pathology: Principles and Practice*; Blackwell Science: United Kingdom, 1999; ISBN 978-1-4443-1403-8.
12. Pedersen, S.; Grønvik, O.; Rødal, M.; Bjørberg, S.; Mattsson, J. *Omfang av byggefeil i Norge*; Menon Economics: Oslo, Norway, 2022;
13. Mundt-Petersen, S.O.; Wallentén, P.; Joelsson, A.; Kläth, M. Distribution and Location of Damages in Swedish Buildings. *J. Phys. Conf. Ser.* **2023**, *2654*,
14. Arditi, D.; Günaydın, H.M. Total Quality Management in the Construction Process. *Int. J. Proj. Manag.* **1997**, *15*, 235–243, doi:10.1016/S0263-7863(96)00076-2.
15. Kvande, T.; Lisø, K.R. *Byggskader. Oversikt*; Byggforskserien 700.110; SINTEF Community: Trondheim, Norway, 2010;
16. Arksey, H.; O'Malley, L. Scoping Studies: Towards a Methodological Framework. *Int. J. Soc. Res. Methodol.* **2005**, *8*, 19–32, doi:10.1080/1364557032000119616.
17. Ingebretsen, S.B.; Andenæs, E.; Kvande, T. Microclimate of Air Cavities in Ventilated Roof and Façade Systems in Nordic Climates. *Buildings* **2022**, *12*, 683, doi:10.3390/buildings12050683.
18. Johansen, K.S. Internal Rain Gutter for BIPV Dimensioning the Internal Rain Gutter for ZEB Laboratory's BIPV Roof. Master thesis, NTNU: Trondheim, Norway, 2019.
19. Park, J.Y.; Lange, J.; Koc, O.; Al-Bakhat, F. Design of an Enhanced Defect Identification System for Commercial Building Construction. In Proceedings of the 2017 Systems and Information Engineering Design Symposium, Charlottesville, USA, 28 April 2017.
20. Chohan, A.H.; Awad, J.; Jung, C.; Ani, A.I.C. Development of Smart Application for House Condition Survey. *Ain Shams Eng. J.* **2022**, *13*, 101628, doi:10.1016/j.asej.2021.10.023.
21. Faqih, F.; Zayed, T. Defect-Based Building Condition Assessment. *Build. Environ.* **2021**, *191*, 107575, doi:10.1016/j.buildenv.2020.107575.
22. Wahab, S.N.A.; Hamid, M.Y. A Review Factors Affecting Building Defects of Structural Steel Construction. Case Study: Student Accommodation in UiTM Perak. *Procedia Eng.* **2011**, *20*, 174–179, doi:10.1016/j.proeng.2011.11.153.
23. Gurmu, A.T.; Krezel, A.; Ongkowijoyo, C. Fuzzy-Stochastic Model to Assess Defects in Low-Rise Residential Buildings. *J. Build. Eng.* **2021**, *40*, 102318, doi:10.1016/j.jobe.2021.102318.
24. Asmone, A.S.; Chew, M.Y.L. Development of a Design-for-Maintainability Assessment of Building Systems in the Tropics. *Build. Environ.* **2020**, *184*, 107245, doi:10.1016/j.buildenv.2020.107245.
25. Hauashdh, A.; Jailani, J.; Rahman, I.A.; AL-fadhali, N. Strategic Approaches towards Achieving Sustainable and Effective Building Maintenance Practices in Maintenance-Managed Buildings: A Combination of Expert Interviews and a Literature Review. *J. Build. Eng.* **2022**, *45*, 103490, doi:10.1016/j.jobe.2021.103490.
26. Felipo, R.; Charpin, D. Structural Home Defects Are the Leading Cause of Mold in Buildings: The Housing and Health Service Experience. *Int. J. Environ. Res. Public. Health* **2022**, *19*, 16692, doi:10.3390/ijerph192416692.
27. Holme, J. Mould Growth in Buildings. Doctoral thesis, NTNU: Trondheim, Norway, 2010.
28. Tarekegn Gurmu, A.; Shooshtarian, S.; Mahmood, M.N. Critical Evaluation of Building Defects Research: A Scientometric Analysis. *J. Perform. Constr. Facil.* **2022**, *36*, doi:10.1061/(ASCE)CF.1943-5509.0001727.
29. Wong, J.T.Y.; Hui, E.C.M. Water Seepage in Multi-storey Buildings. *Facilities* **2005**, *23*, 595–607, doi:10.1108/02632770510627570.

30. Misar, I.; Novotny, M. Defects and Behaviour of Inverted Flat Roof from the Point of Building Physics. In Proceedings of the 8th International Scientific Conference Building Defects, České Budějovice, Czech Republic, 24 November 2016.
31. Aktas, Y.D.; Zhu, H.; D'Ayala, D.; Weeks, C. Impact of Surface Waterproofing on the Performance of Brick Masonry through the Moisture Exposure Life-Cycle. *Build. Environ.* **2021**, *197*, 107844, doi:10.1016/j.buildenv.2021.107844.
32. Braun, V.; Clarke, V. Using Thematic Analysis in Psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101, doi:10.1191/1478088706qp063oa.
33. Lisø, K.; Kvande, T.; Thue, J. High-Performance Weather-Protective Flashings. *Build. Res. Inf.* **2005**, *33*, 41–54, doi:10.1080/0961321042000323798.
34. Kvande, T.; Lisø, K.R. Climate Adapted Design of Masonry Structures. *Build. Environ.* **2009**, *44*, 2442–2450, doi:10.1016/j.buildenv.2009.04.007.
35. Gullbrekken, L.; Kvande, T.; Jelle, B.P.; Time, B. Norwegian Pitched Roof Defects. *Buildings* **2016**, *6*, 24, doi:10.3390/buildings6020024.
36. Kvande, T.; Bakken, N.; Bergheim, E.; Thue, J.V. Durability of ETICS with Rendering in Norway—Experimental and Field Investigations. *Buildings* **2018**, *8*, 93, doi:10.3390/buildings8070093.
37. Ilozor, B.D.; Okoroh, M.I.; Egbu, C.E.; Archicentre. Understanding Residential House Defects in Australia from the State of Victoria. *Build. Environ.* **2004**, *39*, 327–337, doi:10.1016/j.buildenv.2003.07.002.
38. Pamera, S.; Gurmu, A. Framework for Building Defects and Their Identification Technologies: Case Studies of Domestic Buildings in Melbourne, Australia. In Proceedings of The 54th International Conference of the Architectural Science Association, Auckland, New Zealand, 26 November 2020.
39. Lee, J.; Ahn, Y.; Lee, S. Post-Handover Defect Risk Profile of Residential Buildings Using Loss Distribution Approach. *J. Manag. Eng.* **2020**, *36*, doi:https://doi.org/10.1061/(ASCE)ME.1943-5479.0000785.
40. Lee, S.; Lee, S.; Kim, J. Evaluating the Impact of Defect Risks in Residential Buildings at the Occupancy Phase. *Sustainability* **2018**, *10*, 4466, doi:10.3390/su10124466.
41. Plebankiewicz, E.; Malara, J. Analysis of Defects in Residential Buildings Reported during the Warranty Period. *Appl. Sci.* **2020**, *10*, 6123, doi:10.3390/app10176123.
42. Talib, R.B.; Sulieman, M.Z. Identifying Building Defects: From Construction Cases in Malaysia. *Int. Trans. J. Eng. Manag. Appl. Sci. Technol.* **2021**, *12*, doi:10.14456/ITJEMAST.2021.220.
43. Islam, R.; Nazifa, T.H.; Mohammed, S.F.; Zishan, M.A.; Yusof, Z.M.; Mong, S.G. Impacts of Design Deficiencies on Maintenance Cost of High-Rise Residential Buildings and Mitigation Measures. *J. Build. Eng.* **2021**, *39*, 102215, doi:10.1016/j.jobe.2021.102215.
44. Abdul-Rahman, H.; Wang, C.; Wood, L.C.; Khoo, Y.M. Defects in Affordable Housing Projects in Klang Valley, Malaysia. *J. Perform. Constr. Facil.* **2012**, *28*, 272–285, doi:10.1061/(ASCE)CF.1943-5509.0000413.
45. Ahzahar, N.; Karim, N.A.; Hassan, S.H.; Eman, J. A Study of Contribution Factors to Building Failures and Defects in Construction Industry. *Procedia Eng.* **2011**, *20*, 249–255, doi:10.1016/j.proeng.2011.11.162.
46. Jesumoroti, C.; Olanrewaju, A.; Khor, S.C. Defects in Malaysian Hospital Buildings. *Int. J. Build. Pathol. Adapt.* **2022**, doi:10.1108/IJBPA-12-2021-0166.
47. Talib, R.; Sulieman, M. Achieving Zero Defects Strategy: A Quantitative Report Adjudicating the Most Common Building Defects to Look Out For. *Adv. Civ. Eng. Mater.* **2021**, *139*, 189–200, doi:10.1007/978-981-33-6560-5_21.
48. Jonsson, A.Z.; Gunnelin, R.H. Defects in Newly Constructed Residential Buildings: Owners' Perspective. *Int. J. Build. Pathol. Adapt.* **2019**, *37*, doi:10.1108/IJBPA-09-2018-0077.
49. Waziri, B.S. Design and Construction Defects Influencing Residential Building Maintenance in Nigeria. *Jordan J. Civ. Eng.* **2016**, *10*, 313–323, doi:10.14525/JJCE.10.3.3605.
50. Awasho, T.T.; Alemu, S.K. Assessment of Public Building Defects and Maintenance Practices: Cases in Mettu Town, Ethiopia. *Heliyon* **2023**, *9*, e15052, doi:10.1016/j.heliyon.2023.e15052.
51. Wali, K.; Ali, N. Diagnosis and Evaluation of Defects Encountered in Newly Constructed Houses in Erbil City, Kurdistan, Iraq. *Eng. Technol. J.* **2019**, *37*, 70–77, doi:10.30684/etj.37.2A.5.
52. Chew, M.Y.L. Defect Analysis in Wet Areas of Buildings. *Constr. Build. Mater.* **2005**, *19*, 165–173, doi:10.1016/j.conbuildmat.2004.07.005.
53. Sassu, M.; De Falco, A. Legal Disputes and Building Defects: Data from Tuscany. *J. Perform. Constr. Facil.* **2014**, *28*, doi:10.1061/(ASCE)CF.1943-5509.0000520.

54. Forcada, N.; Macarulla, M.; Fuertes, A.; Casals, M.; Gangolells, M.; Roca, X. Influence of Building Type on Post-Handover Defects in Housing. *J. Perform. Constr. Facil.* **2012**, *26*, 433–440, doi:10.1061/(ASCE)CF.1943-5509.0000225.
55. Forcada, N.; Macarulla, M.; Gangolells, M.; Casals, M.; Fuertes, A.; Roca, X. Posthandover Housing Defects: Sources and Origins. *J. Perform. Constr. Facil.* **2013**, *27*, 756–762, doi:10.1061/(ASCE)CF.1943-5509.0000368.
56. Forcada, N.; Macarulla, M.; Love, P.E.D. Assessment of Residential Defects at Post-Handover. *J. Constr. Eng. Manag.* **2013**, *139*, 372–378, doi:10.1061/(ASCE)CO.1943-7862.0000603.
57. Forcada, N.; Macarulla, M.; Gangolells, M.; Casals, M. Handover Defects: Comparison of Construction and Post-Handover Housing Defects. *Build. Res. Inf.* **2016**, *44*, 279–288, doi:10.1080/09613218.2015.1039284.
58. Shirkavand, I.; Lohne, J.; Lædre, O. Defects at Handover in Norwegian Construction Projects. *Procedia - Soc. Behav. Sci.* **2016**, *226*, 3–11, doi:10.1016/j.sbspro.2016.06.155.
59. Dzulkifli, N.; Sarbini, N.N.; Abidin, N.I.; Ibrahim, I.S. Analysis of Building Defects at Residential Collages: A Case Study at Higher Education Facilities N. *ASEAN Eng. J.* **2022**, *12*, 31–39, doi:10.11113/aej.v12.18142.
60. Pan, W.; Thomas, R. Defects of New-Build Dwellings Constucted to Building Regulation and the Code of Sustainable Homes. In Proceedings of the 29th Annual ARCOM Conference, Reading, United Kingdom, 2 September 2013.
61. Chong, W.K.O.; Low, S.-P. Latent Building Defects: Causes and Design Strategies to Prevent Them. *J. Perform. Constr. Facil.* **2006**, *20*, 213–221, doi:10.1061/(ASCE)0887-3828(2006)20:3(213).
62. SINTEF Vår Historie Available online: https://www.sintef.no/om-sintef/var-historie/ (accessed on 9 November 2023).
63. Mansor, R.; Othuman Mydin, M.A.; Ismail, M.; Wan Harun, W.M. Categorization of General Problems and Defects in Historical Building. *Hist. Build.* **2012**, 127–136.
64. Ojo, A.M.; Ijatuyi, O.O. Defective Construction in Residential Buildings: A Study of Sunshine Gardens, Akure Nigeria. *Eur. Cent. Res. Train. Dev. UK* **2014**, *1*, 16–30.
65. Juran, J.M.; Blanton Godfrey, A. *Juran Quality Handbook*; 5th ed.; McGraw Hill: New York, USA, 1951;
66. Atkinson, A.R. The Role of Human Error in Construction Defects. *Struct. Surv.* **1999**, *17*, 231–236, doi:10.1108/02630809910303006.
67. Pheng, L.S.; Wee, D. Improving Maintenance and Reducing Building Defects through ISO 9000. *J. Qual. Maint. Eng.* **2001**, *7*, 6–24.
68. Isa, H.M.; Hassan, P.F.; Takim, R.; Mat, M.C.; Ithnin, Z.I. How Adequate Is Adequate? A Case of the Adequacy in Determining Client Requirements in the Construction of Four Public Hospitals in Malaysia. In Proceedings of the W092-Special Track 18th CIB World Building Congress, Salford, United Kingdom, May 2010.
69. Lisø, K.R.; Myhre, L.; Kvande, T.; Thue, J.V.; Nordvik, V. A Norwegian Perspective on Buildings and Climate Change. *Build. Res. Inf.* **2007**, *35*, 437–449, doi:10.1080/09613210701269438.
70. Lisø, K.R.; Kvande, T.; Time, B. Climate Adaptation Framework for Moisture-Resilient Buildings in Norway. *Energy Procedia* **2017**, *132*, 628–633, doi:10.1016/j.egypro.2017.09.698.