Hindawi
Advances in Civil Engineering
Volume 2022, Article ID 4690073, 21 pages
https://doi.org/10.1155/2022/4690073

*Research Article*

# Post-Handover Quality Management Index of Electric Housing Work

**Junmo Park and Deokseok Seo**

*School of Architecture, Halla University, Wonju-si 26404, Gangwon, Republic of Korea*

Correspondence should be addressed to Deokseok Seo; seodk@halla.ac.kr

Received 2 July 2022; Revised 15 November 2022; Accepted 28 November 2022; Published 14 December 2022

Academic Editor: Zhenmin Yuan



Since housing electrical work is essential in the aspect of electricity use and electrical accidents, it is necessary to properly design, construct, and manage it to avoid quality problems. However, disputes are intensifying in Korea due to numerous quality problems after the house is handed over to the owner. Although related standards have been established and some studies have been conducted, there is a lack of discussion on housing electrical work because the housing quality problem is varied. In this study, the cases of quality problems that occurred in housing electrical works were investigated, while 52 quality control indices were presented and classified according to detailed work category, object, and problematic occurrences. In addition, the number of cases of quality problems for each quality management index and the repair cost ratio were used as a scale to understand the status of quality management. Finally, 11 quality indices were suggested as candidates of important indices which needed to be controlled to focus on the housing electrical work by comparing the above 52 indices. The comparison was made on which one was best suited to the Pareto principle, a quality management strategy, among the candidates for the critical index and the indices suggested by relevant standards and previous studies. The comparison results showed that the candidates of the essential indices suggested in this study conformed to the Pareto principle, while other indices hardly conformed to it. Therefore, if the quality control strategy of choice and concentration for housing electrical works is used, focusing on these vital index candidates can effectively assist in handling the occurrence of quality problems.

## 1. Introduction

The quality of housing is an important index that can express producer competitiveness. If a house of excellent quality meets the consumer's expectations, it ultimately leads to high satisfaction [1]. Customer satisfaction brings a good reputation for the producer and is often settled as a brand representing the producer's image [2]. This good reputation generates a positive effect, such as repurchasing—house built by that producer or recommending to others [3, 4]. The consumer also makes a reasonable purchase to procure excellent quality houses as much as possible. Some consumers sometimes search for better quality housing even if they already possess houses [5]. In addition, there is an argument that housing quality is closely related to socio-economic status [6]. As discussed above, the supply and consumption of excellent quality housing become benefit for producers and consumers.

Therefore, housing producers seek a good evaluation through various gestures after the house's handover to the consumer. The postconstruction quality is evaluated using a criterion, the Customer Satisfaction Survey. The National Housing Building Council (NHBC) and Home Builders Federation (HBF) are housing company organizations in the UK that investigate and publish the satisfaction of house purchasers. According to the survey conducted in 2022 [7], 91% of the house consumers in the UK responded positively that they would recommend those housing companies to others. Such satisfaction of housing consumers increased by 7% during the last five years. However, the Homeowners Alliance (HOA) survey, an organization of homeowners in the UK, showed somewhat different results. According to the survey resulted in 2019 by the HOA[8], 87% of the housing consumers want security, which is not a warranty for defect repair, to be directly deposited. This implies that defect repair is not satisfactory from the viewpoint of the house consumer. Therefore, trust in housing quality should be improved.

In Korea, there are cases in which different standards for housing quality are created and evaluated. The Korea Productivity Center under the Ministry of Trade, Industry and Energy, which is a national institution in Korea, evaluates various aspects of housing quality using a scale called the National Customer Satisfaction Index (NCSI). Among the indices for the housing sector, the housing brand values for the top 8 companies are evaluated. The average index from 2011 till 2021 steadily dropped till 2015 and assumed an increasing trend till 2021 [9]. Since disputes over quality can be regarded as a standard for housing quality, the Defect Review and Dispute Mediation Committee under the Ministry of Land, Infrastructure, and Transport of Korea plays a role in mediating disputes regarding housing defects. The number of disputes received by this Committee by 2021 amounted to 37,116, which is increasing yearly [10]. Considering this, the national customer satisfaction index for housing brand value is rising, but the housing quality perceived by consumers is still insufficient.

Construction, including housing, is executed through a combination of civil, architectural, mechanical, electrical, telecommunication, and landscape works [11, 12]. Therefore, effective management is needed through cooperation and synchronization between sectors [11, 12]. Although efforts are made to optimize design and construction among construction participants, it is challenging to secure satisfactory quality in all aspects [13, 14]. For example, cracks frequently occur due to drying shrinkage in the concrete structure [15]. In the wooden structure, cracking occurs due to changes in moisture content [16]. If appropriate preservative treatment is not given, fungus attacks or damage from insects such as termites occur [17, 18]. In some cases, the joining method of the pipe is not adequate, or the pipe is installed with a material that is unsuitable for use, which leads to leakage earlier than the expected service life cycle of the pipe [19, 20]. As enumerated above, various problems that deteriorate quality may occur throughout the housing.

In the housing's electrical work, various problems also occur. Although the service life of various facilities or electrical cables used in electrical work is not precisely known, these cannot be used forever [21]. Moreover, electrical load or usage differs depending on the household members and their lifestyles [22]. In addition, the problem can occur due to excessive electricity use in a specific season [23]. Therefore, a variety of electrical problems may occur. The short circuit is the most frequently occurring problem in electrical work [24]. Electrical short circuits occur if the electrical wire covering is damaged or defective parts are used [25]. When a short circuit occurs, the circuit breaker operates whenever an electrical device is used [26], making electricity unavailable in all or parts of the house. In this case, the lights are not on, making it challenging to work at night [27], and all foods in the refrigerator may be spoiled [28].

However, the most crucial problem with electric housing work is that it causes fires. Electrical problems account for a large proportion of fire accidents. In the United States in 2019 alone, 50.2% of home fires were caused by cooking and 7.5% were due to electricity-related defects [29]. In the case of the UK, as of 2021, the most significant number of fires were caused by cooking appliances, followed by electrical distribution and electrical appliances [30]. In Korea, as per the statistics in 2020, 27.6% of all fires occurred in housing. Moreover, among the causes of fire, electricity accounted for 24.1% of the total and was the second most crucial cause [31].

In addition, equipment and parts of electrical work contain heavy metals harmful to the human body. Mercury is a luminant in electric lamps and batteries for a small portion [32]. Lead is used to monitor glass and soldering, which does not melt the substrate at a relatively low temperature among welding methods [33]. Bromine is used as a flame retardant to suppress fire [34]. These heavy metals are gradually reduced due to environmental regulations or institutionally banned [35]. However, even a tiny portion of heavy metals can be fatal to the human body. Therefore, environmental and health problems may occur due to waste generated while repairing defects in electric work.

In order to improve the quality problem of the aforesaid housing electrical work, it is necessary to first identify which type of problem occurs. The research trends on the identification and solution of quality problems in housing electrical work are as follows. Conti and Orcioni analyzed the defect rate in components such as thin-film transistor boards and control boards [36]. Shipp et al. identified three common causes by analyzing the defect cause of transformer failure. In addition, an alternative that could alleviate the primary circuit breaker switching transient due to voltage surge was proposed [37]. Considering the environmental load or energy efficiency, solid-state lighting (SSL) has recently drawn the limelight over conventional lighting such as incandescent and fluorescent lamps. However, according to Lall et al., SSL still has quality problems. Remarkably, they pointed out the problems of exposure to heat and excessive moisture due to long-term use, such as landscape lighting installed outside a housing complex. Specifically, they listed the defect types such as carbonization of the encapsulant material, delamination, and lens cracking [38]. During the construction of a house, there is a possibility that moisture may remain in the conduit that is embedded in the concrete.

Furthermore, moisture may exist in the conduit due to dew condensation as temperature changes. In this regard, the study of Hwang et al. pointed out that the Halogen-Free Flame Retardant Poly Olefin Insulation Wire (HFIX wire) in the conduit absorbed moisture, causing the insulation to break down and trip [39]. In the case of a high-rise house, an elevator is essential for residents to move. Therefore, various problems may occur in high-rise houses because the elevator is continuously operated. In the study conducted by Ha, elevator failure data for 17 years were collected and analyzed by time of failure, building use, elevator type, and failure parts. It was found that the most failures occurred in summer season, in houses among building uses, in passenger elevators among elevator types, and in semiconductors in control panels among components [40]. As seen above, studies on major facilities and devices used in electrical works are being actively conducted. However, although they have studied in-depth the equipment that caused defects, they did not go into the overall quality problems that occurred in the housing electrical work.

In Korea, as disputes over housing quality have rapidly increased after handing over a house to the owner, there are standards established to smoothly resolve disputes. These are the construction appraisal practice [41] proposed by the court and the defect judgment standard[42] enacted by the Ministry of Land, Infrastructure and Transport, which oversees the construction sector. However, although the construction appraisal practice deals with overall appraisal, it does not include the housing electrical quality problem in detail. In the case of defect judgment standards too, only some of the quality problems of electrical works are stipulated. Furthermore, there have been very few previous studies conducted on housing electrical works, which will be discussed in detail in Chapter 2. Most of the previous studies conducted on the quality problem of housing electrical works have been limited as part of the equipment [43–50], and there are limited studies that have been conducted focusing on the housing electrical work [51, 52]. Therefore, it is necessary to specify the quality problems that occur in the housing electrical work and to have standards such as the quality management index that can represent whole figure.

In addition, in order to practically use the quality management index, it is necessary to be able to set management goals, and a comparison scale for setting the goals is also required. However, the previous study, which will be described later, failed to suggest a management goal for improving housing quality problems. If there are too many quality problems and it is practically difficult to handle all of them, it is reasonable to select important ones among them and improve them intensively. For that purpose, a comparison scale should be presented as a selection method. However, only some cases proposed the number of defects [43–46, 51], number of cases [52], repair cost [44], etc. as comparison scale in the previous studies. Moreover, there was no case of suggesting a methodology for setting management goals using comparison scales. Therefore, a methodology including the setting of management goals and comparison scale for improving the quality of housing electrical works should be proposed.

In order to achieve the above agenda, in this study, the quality management index that describes the quality problems occurred in the housing electrical work after handover the house to the owner in detail is proposed to help the overall quality problems to be identified quickly. In addition, it is necessary to propose a method of comparing quality management indices as a comparison scale for each quality management index by adopting number of dispute cases and the defect repair cost ratio, and then combining these. Through this process, it would be possible to understand the status of the housing electrical work, and it can derive a method for selecting an important index. Finally, by comparing the important indices proposed in this study with those presented in each standard and literature, a quality management strategy that best meets the status of housing electrical construction is proposed.

## 2. Literature Study

*2.1. Quality Management Index.* For the quality problems in the housing electrical work, it is possible to establish a quality management index that can identify the overall problem by specifying the problem by identifying types and amount of problem. However, in most cases, quality problems are unfavorable to housing producers, and it is not easy to obtain relevant data. Even in major previous studies on housing quality issues, it is often found that the source of the research data is unclear or not specified at all, and in some cases, the relevant institutions refuse to provide the data.

If we look at how the quality management index is stipulated in the standards for dealing with quality issues, the Society for Construction Lawsuit in Seoul Central District Court in Korea has established a guideline called Construction Appraisal Practice (CAP) that includes housing quality issues [41]. Since the construction appraisal practice provided guidelines for litigation, it was expected that the litigation data would be the basis. However, in the construction appraisal practice, types, depth or level, and amount of collected data were not described at all. In construction appraisal practice, the quality management index for electrical work consists of three items: (1) no flexible conduit installed inside the bathroom ceiling, (2) defective built-in appliances, and (3) defective lighting fixtures. As another standard, the Ministry of Land, Infrastructure and Transport of Korea established the Defect Dispute Mediation Committee to deal mainly with housing quality disputes. In this committee, defect dispute mediation is being carried out using what is called A Judge Standard, investigated the method, and estimated costing of Defect in dwelling House (JSDH) [42]. There is a difference between the above two standards: the construction appraisal practice is mainly used in cases where disputes are resolved through litigation, and the defect judgment standards are used for resolving disputes through mediation. In the defect judgment standard, the quality management index for housing electrical work is defined as 6 categories of (1) non-installation of flexible conduit inside the bathroom ceiling, (2) poor lighting, (3) defect in lighting grounding, (4) installation of lighting equipment different from the drawings, (5) detachment of lighting, and (6) unconnected lighting.

However, as will be described later in Sections 4.3 and 4.4, the quality management index of construction appraisal practice and defect judgment standard seems to have limitations, although these are standards based on dispute cases, that it is extremely limited compared to reality. In addition, no standard discloses the basis or method of selecting the quality management index for the housing electrical works. They focus only on investigating defects using the quality management index, and do not suggest directions or methods for improving quality management. From a generality point of view, the quality management index intensively manages the cases where defects occur frequently or the cost of repairing damages is high [53]. Therefore, it is difficult to consider these standards themselves as goals for quality improvement.

Next, we will look at what data were used to derive quality management index while the major previous studies worked on the quality management index. Similar studies have been conducted on concrete exterior house wall defects [54], defects in housing mechanical equipment [55, 56], and landscaping defects in apartment complexes [57]. The research trends for housing electrical work are as follows. Georgious et al. requested data from the Housing Guarantee Fund Ltd. (HGF), an Australian housing quality assurance agency, and the Royal Australian Institute of Architects (RAIA), which conducts a quality survey to investigate the quality problems of Australian housing. However, HGF refused to provide data on the grounds of commercial secrecy. Therefore, Georgious et al. stated that they utilized the housing inspection report for the housing quality problems of Archicenfre, under the RAIA Institute of Architecture as data [43]. Taking their statement on the research, the data used by Georgious et al. appear to have a high-level expertise and objectivity. Meanwhile, Georgious et al. classified defects in 1,772 houses in Australia by dividing them into works inside of housing complexes, exterior work, and interior work. They classified 12 types of detailed defects. However, the electrical work was not separately classified, and the mechanical work and the electrical work were grouped and classified as facility work. In addition, they disclosed that 9 types, including broken/deteriorated, were identified among 12 types of defects in the housing facility work. However, among them, it is impossible to find out how many defects occurred in the electrical work, and the specific object or phenomenon was not described.

The study by Kim et al. was based on the data from 1,769 housing units in Korea where residents requested defect repair [51]. However, since residents are not housing experts, it is difficult to regard that the data presented by them accurately stipulates the quality problem. Even in litigation, problems of use or disputes between residents are sometimes claimed as defects, so in order to utilize the data presented by residents, it is necessary to go through a review by a related expert. However, in the paper by Kim et al., it was not stated that research was conducted based on the data arranged through such process. Meanwhile, Kim et al. divided housing electrical works into five groups: electricity, telecommunication, firefighting, TV public watching, and other works. However, it is not reasonable to classify them as electrical works from the fact that the Korean Housing Act classifies communications, firefighting, and TV public watching as separate works in addition to electrical work, and orders for these works are raised separately. On the other hand, Kim et al. divided the defect types of electrical works into defects in design stage and defects in construction stage. In the design stage, four types of defects were presented, such as different cable specifications and lightning protection equipment specifications, and eight types of defects such as outlet defects and switch failures were presented as defects in the construction stage.

Lee's study targeted 16,631 housing units in Korea and indicated that he analyzed data from a defect-related institution, but he did not disclose the source [44]. Lee divided housing works into architecture, civil engineering, machinery, electricity, communication, and firefighting, and suggested the type of defect for each work type. Among them, electrical work was divided into seven categories, such as poor lighting and poor location. Lee suggested lighting and elevators as specific subjects for the quality problem, but other things are not clearly specified. Meanwhile, Lee revealed that he put all other items as other works other than the quality management index he proposed, and the repair cost of these other works accounted for 43.6% of the total. Therefore, even if it is judged based on the data presented by Lee, Lee's quality management index for electrical work may not be a representative.

Yu has researched 2,297 households in Korea, revealing that, like the previous study by Kim et al., the study was performed based on the data requested by residents to repair defects [45]. In addition to electrical work, Yu also includes architectural and mechanical fields. Yu classified the quality management index of electrical works into 9 types: general defects, lighting failures, lighting cover breakages, and switch failures. However, there was no specification on what the general defect defined by Yu means. Moreover, the repair cost of general defects accounted for 55% of the electrical work, and it seems that Yu's classification of the quality management index for electrical works is inappropriate same as in Lee's study.

Forcada et al. classified 2,179 housing complexes in Spain into defects that occurred within the housing complex, defects that occurred outside the building, and defects occurred inside the building [46]. However, according to Forcada et al., it was suggested that these quality problems were difficult to represent as they were constructed by one contractor. Therefore, the data of Forcada et al. appear to be based on the data presented by the housing producers. Meanwhile, Forcada et al. classified electrical works as facilities along with mechanical works. In addition, the quality management index of electrical works defined the target as electrical fixtures and lighting devices (electrical light and power), and the study does not include information on problematic phenomena.

Choi conducted study on 48 complexes in which lawsuits regarding quality issues were filed against housing in Korea [47]. The litigation in Korea is based on the investigation on the quality issues by the court-appointed experts such as architects and technicians. Therefore, just like the study of Georgious et al., the data used by Choi seems reasonable in terms of professionalism and objectivity. Meanwhile, Choi studied the warranty period and repair cost for quality problems. This was for the entire house and included electrical works, but it did not suggest a specific quality management index for electrical works.

Love et al. targeted 217 Australian building, infrastructure, and rail projects, based on data provided by producers [48]. They compared each project entity, size of defect repair cost, detailed construction work, and cause of defects. The project entity was divided into owner, designer, general contractor, and sub-contractor, and detailed facilities were classified into 22 categories. Among them, electricity-related work was divided into two categories: electrical work and lighting work.

Chisholm analyzed the effects of quality problems of house on health and safety of residents by interviewing 83 homeowners in New Zealand [49]. Chisholm's study is meaningful that it was a study conducted from the viewpoint of residents, mainly in terms of health and safety of the residents. However, because the evaluation of residents lacked technical expertise, the quality management index based on that survey has limitations. In fact, among the quality control indices suggested by Chisholm, for electrical works, it was limited to electric power supplies, switches, and home appliances, and quality problems were simply classified by location. In addition, there was no specific classification by phenomenon.

Park et al. derived a quality management index in their study for housing electrical works based on lawsuits filed in Korea [52]. The quality management index for electrical works suggested by Park et al. was subdivided into 29 types, and these are listed in Table1, which will be described later. Park et al. only targeted housing electrical works and presented the largest quality control indices among the previous studies. This study has further subdivided the quality management index by Park et al. for housing electrical works.

The study by Chohan et al. was related to the method of investigation of the quality problem of housing in Malaysia [50]. However, they did not disclose the specific study subjects. They classified 10 building defects according to the location of the house and further subdivided them into 55 house defects. Among them, electrical works were classified as service defects, and the quality management index defines only one, electrical fixtures and switches.

Summarizing the results of the review of the previous studies above, it is necessary to secure objective data to approach the quality problem of housing electrical works, but such cases seem to be rare. The research based on the data investigated by experts such as Georgious et al. and Choi looks more objective. Also, as most of the studies dealt with housing quality issues, the quality management index for electrical works was limited. Therefore, in order to rationally derive the quality management index for housing electrical works, objective data should be secured, and the contents related to electrical work should be abundant. This study intended to present a quality management index using data from litigation on housing quality issues in Korea.

*2.2. Comparative Measures and Application.* If the quality management index of the housing electrical works has been selected, it is necessary to identify the quality management level of the housing electrical work to use the quality management index, set a management goal that matches it, and prepare an achievement strategy. As mentioned above, only the quality management index itself is to be used in the quality dispute-related standards, and the quality management measures that developed the quality management index was not presented. Therefore, in this section, the quality management measures suggested in the previous studies will be reviewed.

Georgious et al. used the defect rate as a scale to express the quality management index, but they did not include the number of cases or repair costs [43]. Also, they emphasized the sharing of knowledge and information among housing-related institutions, associations, universities, and cooperatives, but failed to suggest specific goals or methods for quality improvement.

Kim et al. performed a study based on the repair request data of residents. However, even if all of them were considered quality problems since they did not use the number of other cases or repair costs, no goals or alternatives combining these indices were presented [51]. Nonetheless, they suggested the cause and improvement measures of quality index for each electrical work. Kim et al. presented only the status of problem occurrence, which has limitations based on applications from non-professional residents. Moreover, they did not include the process of separately analyzing the cause of the problem and deriving improvement measures in their research, nor did they cite the diagnosis by a separate expert to identify the cause or suggest countermeasures.

Lee's study used the number of occurrences of quality problems and the repair cost as scale for the quality management index [44]. In addition, the excess and shortage of repair costs were compared for each space where the problem occurred and the detailed construction work. Lee has proposed the supplemented quality control checklist of the housing producers as a plan for cause of defect occurrence and improvement. However, as with Kim et al. above, the study did not include any intermediate steps that were connected to the results of Lee's analysis and subsequent causes of defects or improvement measures. The study by Yu [45] was not much different from that of Kim et al. or Lee.

The study by Forcada et al. did not focus on comparison or evaluation between quality management indices, but compared defects identified by the builder at the time of housing construction with those identified by residents after handover [46]. Accordingly, it was shown that there is a difference in quality standards in view of the different eye level of the builder and the occupant. However, Forcada et al. did not set specific quality management goals, and the mentioned alternatives were just ordinary ones and had no direct relationship with the analysis content.

Choi's study compared repair cost and home warrant deposit as indices for quality management [47]. As a specific quality management goal, it was suggested as a research question whether the repair cost would exceed the home warranty deposit, and in the result of the case analysis, the repair cost was below the defect deposit standard. However, it was for the whole housing quality problem, and there was no particular about the electrical work.

The study by Love et al. compared the difference in repair cost according to the type of project and suggested that the repair cost due to quality problems was about 6 times higher than the initial construction cost [48]. It was also suggested that the difference was mostly due to ordering or design problems. However, it was for the construction industry in a

Table 1: Quality management item of index *D*.

| Code | Object | Phenomena | | Similar item within index *A* |
|---|---|---|---|---|
| | | In regulation | Others | |
| *D*1 | Flexible wireway in ceiling | | Non-installation | *A*1 |
| *D*2 | Wire and cable | Exposure | | *A*2 |
| *D*3 | Wire and cable | Malfunction | | *A*3 |
| *D*4 | Wire | | Short-circuit | *A*4 |
| *D*5 | Cable tray bonding jumper | | Non-installation | *A*33 |
| *D*6 | Outlet box and cover | Malfunction | | *A*11 |
| *D*7 | Outlet box and cover | | Non-installation | *A*12 |
| *D*8 | Wire box and cover | Exposure | | *A*13 |
| *D*9 | Wire box and cover | | Non-installation | *A*14 |
| *D*10 | Electric joint cover | | Non-installation | *A*15 |
| *D*11 | Lighting | Malfunction | No lit | *A*19 |
| *D*12 | Lighting power | | | *A*26 |
| *D*13 | Lighting | | Differenced installation with drawing and specification | *A*20 |
| *D*14 | Lighting | Fault of attachment | | *A*21 |
| *D*15 | Lighting | | Drop out | *A*27 |
| *D*16 | Lighting | | Non-installation | *A*22 |
| *D*17 | Lighting | | Short-circuit | *A*23 |
| *D*18 | Lighting equipment | Breakage | | *A*24 |
| *D*19 | Lighting equipment | | Overheating, destruction | *A*25 |
| *D*20 | Lighting switch | Malfunction | | *A*28 |
| *D*21 | Heliport beacon | Malfunction | | *A*30 |
| *D*22 | Electric outlet and cover | | Non-installation | *A*31 |
| *D*23 | Electric outlet and cover | | Installation fault | *A*32 |
| *D*24 | Electric circuit breaker | Malfunction | | *A*35 |
| *D*25 | Electric circuit breaker | | Non-installation | *A*36 |
| *D*26 | Elevator | | Non-installation | *A*43 |
| *D*27 | Built-in home appliance | Malfunction | | *A*43 |
| *D*28 | Electric pipe hole | | Non-installation | *A*10 |
| *D*29 | Electric wastes | | Waste and neglect | *A*8 |

whole, and a detailed comparison of electrical works was not included.

Chisholm's study was a comparison scale for the housing quality management index, and unlike other studies, it was based on the satisfaction of homeowners [49]. However, his study also did not suggest specific goals, nor did it suggest alternatives specific to electrical work.

The study by Park et al. used the number of defective cases as a comparison scale for the quality management index of housing electrical works [52]. Through the study, quality management indices could be compared with each other, and relatively important indices could be distinguished. However, since this study was based only on the number of cases, there was a limitation that it was impossible to determine the magnitude of damage each quality management index caused because a scale such as repair cost was not used.

In summary, the study which suggest a specific comparison scale for using the quality management index was rare. In some studies, the number of defects, the number of cases, the cost of repairs, and questionnaires or interviews were presented as comparison scale, but previous studies interpreted them as they were and could only use them fragmentarily. So, there was a limitation that those could not propose a new evaluation index by appropriately combining comparison scales, nor even suggest a quality management goal accordingly. Therefore, it is necessary to present a standard that can compare the quality management index of housing electrical works, and to present a new evaluation index or management goal that combines them.

## 3. Materials and Methods

*3.1. Framework.* This study consists of five parts according to the framework of Figure 1, and accordingly research was carried out sequentially. Specific targets, data collection and analysis methods for this purpose are described in the next section.

(1) Data collection: Collects information such as items and types of defects in housing electrical works listed in related regulations, previous studies, and housing defect dispute cases.

(2) (2) Preparation of Quality Management Index (QMI): Preparing QMI by classifying defects according to detailed work, object, and phenomenon from the data collected in (1). The example shown in Figure 1 is described in *A*1, which is the QMI preparation process for the non-installation of flexible conduit in the ceiling. In *A*1, detailed work is

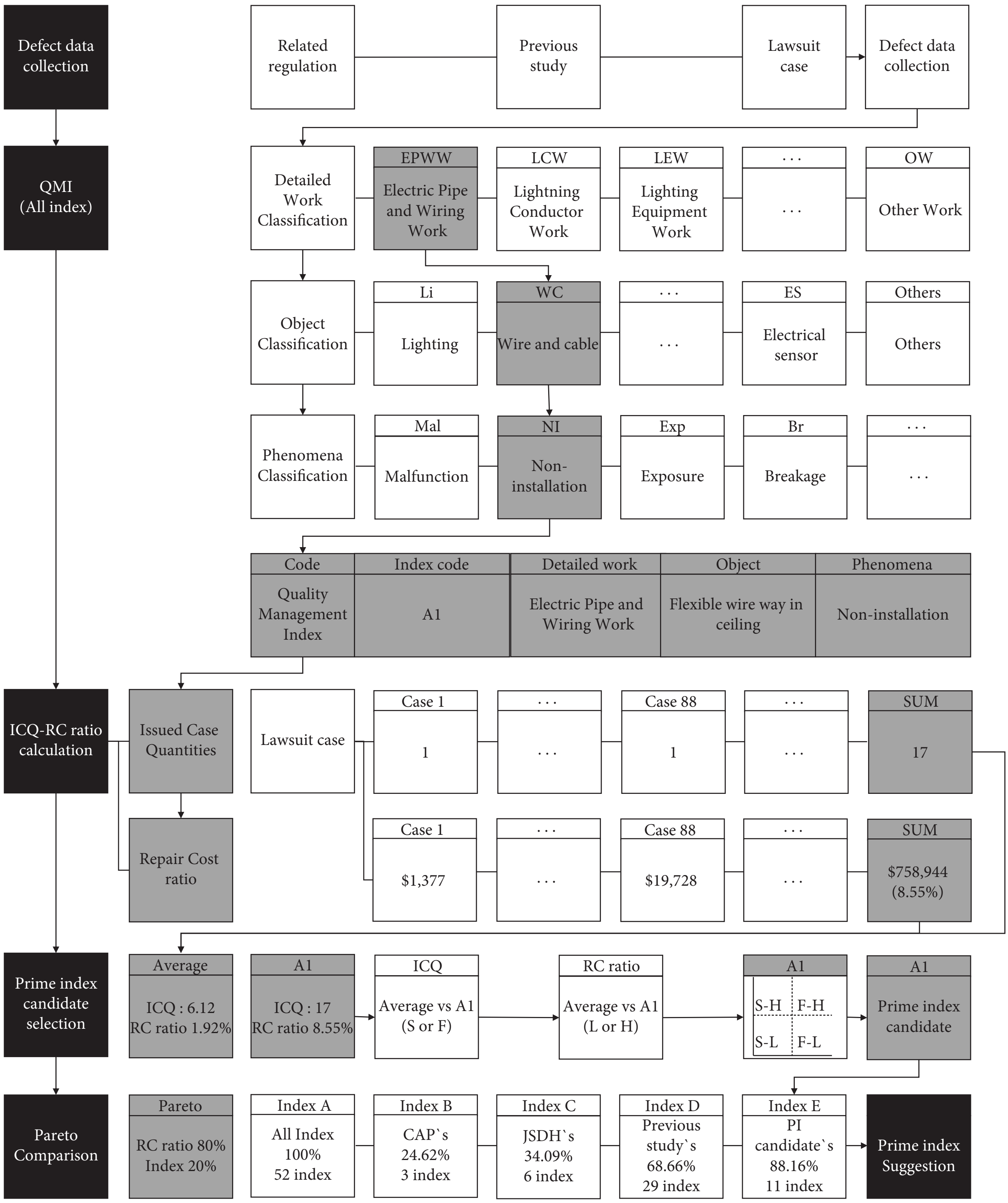


Figure 1: Research framework.

classified as conduit work, objects as electric wires and cables, and status as non-construction. These QMIs can be confirmed in Table 2, which will be discussed later.

(3) Calculation of Issued case quantities (ICQ) and Repair cost ratio to total cost (RC ratio): If defects are confirmed in the case data for each QMI in (2), they are counted as ICQ, and the repair cost is counted as RC and RC ratio. The example shown in Figure 1

Table 2: Quality management item of index $A$.

| Detailed work | Code | Object | Phenomena | |
|---|---|---|---|---|
| | | | In regulations | Others |
| Electric pipe and wiring work | $A1$ | Flexible wireway in ceiling | | Non-installation |
| | $A2$ | Wire and cable | Exposure | |
| | $A3$ | Wire and cable | Malfunction | |
| | $A4$ | Wire | | Short-circuit |
| | $A5$ | Wire and cable | Breakage | |
| | $A6$ | Wire and cable | | No lit |
| | $A7$ | Wire and cable | | Differenced installation with drawing and specification |
| | $A8$ | Electric wastes | | Waste and neglect |
| | $A9$ | Wire and cable | | Leakage |
| | $A10$ | Electric pipe hole | | Non-installation |
| | $A11$ | Outlet box and cover | Malfunction | |
| | $A12$ | Outlet box and cover | | Non-installation |
| | $A13$ | Wire box and cover | Exposure | |
| | $A14$ | Wire box and cover | | Non-installation |
| | $A15$ | Electric joint cover | | Non-installation |
| | $A16$ | Wire box and cover | Corrosion | |
| | $A17$ | Cable tray and duct | Malfunction | |
| | $A18$ | Name tag and directional sign | | Error |
| Lighting equipment work | $A19$ | Lighting | Malfunction | |
| | $A20$ | Lighting | | Differenced installation with drawing and specification |
| | $A21$ | Lighting | Fault of attachment | |
| | $A22$ | Lighting | | Non-installation |
| | $A23$ | Lighting | | Short-circuit |
| | $A24$ | Lighting equipment | Breakage | |
| | $A25$ | Lighting equipment | | Overheating, destruction |
| | $A26$ | Lighting power | | No lit |
| | $A27$ | Lighting | | Drop out |
| | $A28$ | Lighting switch | Malfunction | |
| | $A29$ | Lighting finishing | Malfunction | |
| | $A30$ | Heliport beacon | Malfunction | |
| Electrical equipment work | $A31$ | Electric outlet and cover | | Non-installation |
| | $A32$ | Electric outlet and cover | | Installation fault |
| | $A33$ | Earthing | | Non-installation |
| | $A34$ | Earthing | Malfunction | |
| | $A35$ | Electric circuit breaker | Malfunction | |
| | $A36$ | Electric circuit breaker | | Non-installation |
| | $A37$ | Circuit-breaker | | Non-installation |
| Incoming transfer system work | $A38$ | Transformer and attachment | Malfunction | |
| | $A39$ | Transformer and attachment | | Non-installation |
| Power distribution work | $A40$ | Distribution board and attachment | Malfunction | |
| Electric generator work | $A41$ | Emergency generator and attachment | Malfunction | |
| | $A42$ | Emergency generator and attachment | | Non-installation |
| Elevator and hoist equipment work | $A43$ | Elevator | | Non-installation |
| | $A44$ | Elevator main device | Malfunction | |
| | $A45$ | Elevator attachment | Malfunction | |
| | $A46$ | Elevator finishing | Malfunction | |
| Other work | $A47$ | Electric capacity | | Shortage |
| | $A48$ | Electrical circuit | | Error |
| | $A49$ | Electrical sensor | Malfunction | |
| | $A50$ | Electrical sensor | | Non-installation |
| | $A51$ | Electrical waste | | Abandonment |
| | $A52$ | Built-in home appliance | Malfunction | |

describes the process of aggregating the ICQ, RC, and RC ratios for *A*1.

(4) Selection of Prime Index Candidate (PIC): The method of selecting a PIC among the QMIs in (2) is indicated. In (3), the ICQ and RC ratios aggregated for each QMI are set for each axis of the two-dimensional plane, and the QMI position is marked on the corresponding plane. The RC ratios for the QMI groups in each quadrant are aggregated. Figure 1 shows the process of classifying the quadrant where *A*1 is located. In this study, the important item index was constructed focusing on items with frequent defects and high maintenance cost (items belonging to *F-H* quadrant) and items with infrequent defects but high maintenance cost (items belonging to *S-H* quadrant).

(5) Pareto comparison: The PI of the Housing Electrical Corporation is selected according to the results of Pareto comparison with each QMI presented in related regulations and previous studies, and the PIC selected in (4) above. From the case data collected in (1) above, the RC ratio of QMI stipulated in related regulations and previous studies is aggregated. By comparing these and the RC ratio of the PIC derived in (4), it is analyzed whether it is the most consistent with the Pareto law.

*3.2. Object.* Electrical work in this study means placing facilities and equipment for electricity use in a house and installing piping and wiring. The Korean Housing Act broadly classifies 18 types of facility work according to each part of the house and construction and subdivides each facility into 80 types [58]. Among them, electrical work is classified as the 16th work. In addition, electrical works are subdivided into Electric Pipe and Wiring Work, Lightning Conductor Work, Lighting Equipment Work, Power Equipment Work, Incoming Transfer System Work, Power Distribution Work, Electrical Equipment Work, Electric Generator Work, and Elevator and Hoist Equipment Work.

This study specified multifamily housing among various types of housing. For multifamily housing, the subject of this study, the law stipulates that these multifamily houses must comply with the basic design standards set by the government [59]. Since multifamily houses have parallel quality standards, there is a high probability that defects will occur in similar types and targets. Therefore, a statistically significant result can be expected from comparing defects in apartment houses. In addition, multi-family houses are relatively easy to obtain data because of the large number of houses being built.

*3.3. Case Collection.* This section describes the first stage of the framework in Figure 1 above. As discussed in the previous Chapter 2, some of the definitions for the object and phenomena of the quality problems in the related regulations and previous studies on the housing electrical works were quoted. The detail can be checked from 4.3, 4.4, and 4.5, which will be described later.

Meanwhile, the quality dispute case data was analyzed again based on the data used by Park and Seo [52]. The data were from lawsuits filed against housing quality in Korea. This document investigated quality issues after the home was handed over to the owner. The court appoints a separate construction field expert to investigate and report housing quality issues. The expert who performs this task is called an appraiser. The appraiser checks the quality problem, decides the repair method and scope by work type and location, and calculates the repair cost. These results are included in the appraisal report and submitted to the court [60]. The court makes a judgment by adopting some of the contents of the appraisal report and rejecting others. In general, items related to electrical work and repair costs are specified in the litigation judgment, but in some cases, they are not separately stated [61]. Therefore, this study extracted necessary data from judgments and appraisal reports of housing quality dispute lawsuits.

*3.4. Standardization of Quality Management Index.* This section describes the second stage of the framework in Figure 1 above. The Housing Quality Management Index (QMI) used in the lawsuit is named by the party who raised the issue. However, homeowners lack professionalism, making terminology and expression methods vary significantly from case to case; therefore, the items listed in the collected data were not standardized. This study extracted items related to electrical work from case data, and similar items were mutually adjusted and integrated. According to the work type, objects, and phenomenon, these standardized items are called the quality control indices, and the subject includes electrical facilities and equipment. For example, a wire and cable, pipe, lighting, outlet, circuit breaker, etc., represent electrical facilities or equipment. A phenomenon is a specific problem considering defects, including malfunction, breakage, non-installation, etc. Each QMI detail can be confirmed in Table 2, which will be described later.

*3.5. Measure of Quality Management Index.* This section describes the third stage of the framework in Figure 1 above. This study proposed a management system with the prime index at the center to utilize the quality control index for electric works. The number of disputed cases (ICQ: Issued Case Quantity) and the repair cost ratio (RC ratio: Repair Cost Ratio to Total Cost) were used to evaluate the prime indices.

The number of dispute cases was counted as in equation (1), with 1 being the case where a defect occurred in each index among all cases and 0 being no defect occurrence. Therefore, since the number of study cases was 100, the number of disputed cases ranged from 0 to 100. If the number of dispute cases for a specific index was large, it could be regarded that defects occurred frequently.

$$\mathrm{ICQ} = C_1 + C_2 + C_3 + \cdots C_n. \tag{1}$$

The repair cost ratio was calculated in equation (2) as a percentage obtained by dividing the repair cost of each index by the sum of the repair costs for electrical work. Accordingly, the repair cost ratio ranged from a minimum of 0% to a maximum of 100%. If the repair cost ratio of a specific index was high, it caused much damage.

$$\text{RC ratio} = \frac{\text{Repair cost of the item}}{\text{Total repair cost}} \times 100\,(\%). \qquad (2)$$

On the other hand, since the case data in this study were obtained from the lawsuit, the timing of the determination of defects and repair costs was different. Since the repair cost should consider the difference over time, it is necessary to organize it under a consistent standard. As of the current time when this study is conducted, the repair costs for all cases had already been determined in the past. Therefore, the repair cost of each case was converted using the Future Value (FV) method as of the end of December 2021 at the time of the study. As in equation (3), the future value could be calculated by assuming the discount rate (Interest: $I$) and the elapsed period (Year: $n$) between the present value (PV) and the base point as in equation (3). For the discount rate, the three-year interest rate of 1.8% on treasury bonds (KTB) announced by the Central Bank of Korea was applied [62].

$$\text{FV} = \text{PV} \times (1 + i)^n. \qquad (3)$$

*3.6. Prime Index Candidate Draw.* This section describes the fourth stage of the framework in Figure 1 above. In this study, selecting the prime index among the quality control indices of housing electrical works was applied using the method proposed by Park and Seo's study [53] that applied the Pareto principle. As shown in Figure 2 below. Each QMI is expressed as a scatter plot according to the number of dispute cases and the ratio of repair costs. Moreover, it is divided into *S-L*, *F-L*, *S-H*, and *F-H* based on the arithmetic mean value of the number of dispute cases and the ratio of repair costs. Afterward, the number of dispute cases and the level of the remuneration ratio of the index belonging to each quadrant were checked.

In the case of QMI belonging to the *F-H* area, it can be important because the number of dispute cases is significant on average, and at the same time, if a problem co-occurs, a high defect repair cost is required. On the other hand, QMI belonging to the *S-L* area is insignificant because the number of dispute cases is small and the defect repair cost is also low. Therefore, between the contrasting QMI on the *F-H* area and the QMI on the *S-L* area, the one that meets the critical index will be the QMI on the *F-H* area.

Although QMI belonging to the *S-H* area is not a frequent problem, its repair costs are high if it does occur. On the other hand, although QMI belonging to the *F-L* area is a frequently occurring problem, it requires a minor repair cost. Unlike *F-H* and *S-L*, where importance can be clearly distinguished, it is difficult to assert which one is more important in these two cases. Therefore, the one with the higher total defect repair cost ratio of the QMI in each quadrant may be given priority, or, in some cases, both may be adopted as an essential index.

If the number of these critical indices was around 20% of the total index, and the sum of the repair cost ratios accounted for more than 80% of the total repair cost ratios, it was judged that this met the typical Pareto law [63, 64]. Conversely, it was checked whether the trend was consistent with the long-tail law, which was contrary to it [65, 66]. If the quality management system for electric housing works follows the trend of Pareto's law, it is adequate to perform quality control based on important indices for electric housing works. Conversely, if the distribution according to the extended tail theory is shown, it is necessary to devise measures to improve quality control throughout the electric housing work.

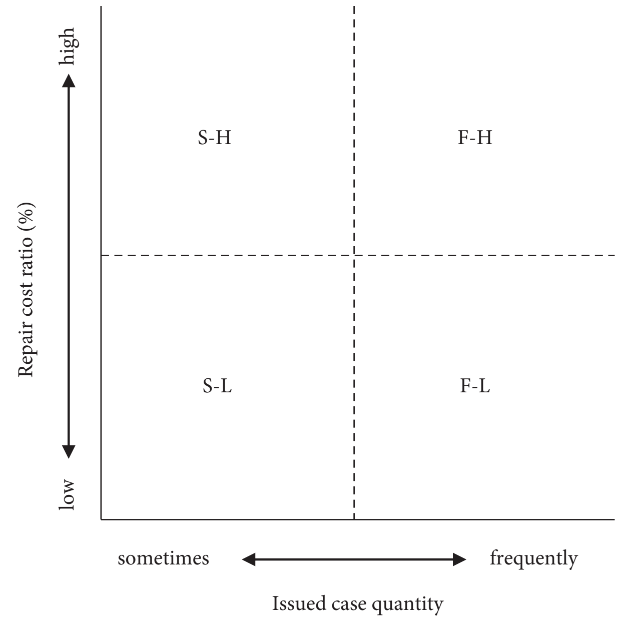

Figure 2: Research framework.

*3.7. Comparison on Index.* Lastly, this section describes the fifth stage of the framework in Figure 1 above. The method of verifying whether the vital index derived in this study is appropriate by comparing the electric work quality control index is as follows. Based on Index *A*, which was the entire case, the construction appraisal practice (CAP) was compared with Index *B*, and the defect determination standard (JSDH) was used as Index *C*. Index *B* and Index *C* were used as standards for handling housing quality disputes in Korea. It was expected that by comparing them, the level of standards could be understood, and suggestions for systematic supplementation could be proposed. In addition, Park and Seo [20], which had the most subdivided index among the preceding studies, was named Index *D* and added as a comparison subject. Index *A*, the three indices to be compared, and the candidates for the prime index of this study were named and compared as Index *E*. The ratio of the number of indices to Index *A* (index ratio to Index *A*) and the composition of the repair cost ratio were examined to see which one best fitted Pareto's law. Moreover, the result was selected as a prime index representing the quality management system of the electric housing works.

## 4. Results

*4.1. Outline.* As indicated in Figure 3, the study case was 100 apartment housing complexes in South Korea, with 991 dwelling buildings and 81,431 households. They have been used for 1 to 10 years after the house was completed. Geographically, they were often located in Seoul, Incheon, and Gyeonggi-do, Korea's capital areas. In these cases, 439 items were identified for disputes regarding electrical work. The total repair cost confirmed by a lawsuit judgment was 1.47 billion KRW, and when the exchange rate as of the end of December 2021 was applied, it amounted to 1.26 million USD (1 USD = 1,179 KRW).

*4.2. Standardization: Index A.* For Index *A*, collected cases were reviewed and defined the quality dispute items occurred in the houses as QMI according to detailed construction work, object, and phenomenon. The results were classified into 52, as shown in Table 2.

Figure 4 shows the QMI of Index *A* according to the type of detailed work as per the Housing Act in Korea. As a representative, Electric Pipe and Wiring Work were the most common with 18 cases (*A*1~*A*18). Lighting Equipment Work followed with 12 cases (*A*19~*A*30). On the other hand, there was no corresponding QMI in Lightning Conductor Work and Power Equipment Work. In addition, the six sub-indices (*A*47–*A*52), which are difficult to classify as detailed works stipulated by the Korean Housing Act, were classified as other works. These are sensors attached to equipment, devices, etc. or those classified as design defects.

Figure 5 shows the QMI of Index *A* by object. Lighting was the most common with 12 (*A*19~*A*30), and Wire and pipe was classified into 10 (*A*1~*A*10).

Figure 6 presents QMI of Index *A* by phenomena. Malfunction was the largest with 17 followed by Non-installation with 14.

Figure 7 shows the aggregation of the number of dispute cases (ICQ) for QMI in Index *A*. Lighting malfunction (*A*19) occurred in 42 cases out of 100 cases and occurred most frequently. As for the number of dispute cases in Index *A*, the arithmetic mean was 6.12, with 15 sub-indices exceeding the average and 37 sub-indices below the average, indicating that there were many sub-indices below the average.

Figure 8 shows the ratio of repair ratio to QMI of Index *A*. The elevator main device malfunction (*A*44) took the most repair cost. It was found that the arithmetic mean of the repair cost ratio of each QMI was 1.92%. There were 10 QMIs above the average and 42 sub-indices below the average. Therefore, there were more QMIs with less than average repair cost ratio.

*4.3. Index B.* Table 3 shows Index *B*, which is the electrical work QMI specified in the construction appraisal practice [42]. It consists of a case of no installation of a flexible conduit inside the bathroom ceiling (*B*1), a case of defective built-in home appliance (*B*2), and defective lighting equipment (*B*3).

Figure 9 shows a Pareto graph depicting the repair cost ratio percentage for each Index *B* subindex among the collected cases. *B*0 was the sum of all items not specified in Index *B*. Among the codes of Index *B*, the repair costs were in the sequence of 16.07% for *B*3, 8.55% for *B*1, and 0% for *B*2. The sum of the repair cost ratios for the subindices in Index *B* was 24.14%. On the other hand, *B*0, not included in Index *B*, reached 75.86%.

*4.4. Index C.* Table 4 shows Index *C*, which is the housing electrical work QMI specified in the defect judgment standard [43]. It consisted of six cases of non-installation of a flexible conduit inside the bathroom ceiling (*C*1), poor lighting (*C*2), poor lighting grounding (*C*3), installation with a lighting fixture different from the design drawing (*C*4), lighting missing (*C*5), and unconnected lighting (*C*6).

Figure 10 is a Pareto graph showing the repair cost ratio for each subindex of Index *C* among research cases. *C*0 is the sum of all other defects not specified in Index *C*. In Index *C*, *C*2 had the highest value at 16.07%, *C*4 at 8.99%, *C*1 at 8.55%, and so on. The repair cost ratio for the subindices in Index *C* was 34.09%. On the other hand, *C*0 not included in Index *C* was 65.91%. It was confirmed that the repair cost ratio of the indices belonging to the defect determination criteria was higher than that of the construction appraisal practice.

*4.5. Index D.* Table 1 shows Index *D*, which is the housing electrical work QMI defined by Park and Seo [53]. Index *D* consists of a total of 29 QMIs, as shown in Table 1.

Figure 11 shows the Pareto graph with the repair cost ratio of Index *D*. *D*0 is the sum of all defects not specified in Index *D* and accounted for 31.34%. Among Index *D*, *D*11 was the highest at 16.02%, followed by *D*23 at 12.3% and *D*13 at 8.99%. The sum of all repair cost ratios of Index *D* is 68.66%.

*4.6. Index E.* As mentioned in Section 3.6, Index *E* was selected as an essential index candidate by comparing the number of dispute cases (ICQ), and the repair cost ratio (RC ratio) among the QMIs of Index *A*. Figure 12 below shows each QMI as a scatter plot with the number of dispute cases on the *X*-axis and the repair cost ratio on the *Y*-axis. In addition, the comparison results by dividing into each quadrant based on the average of the number of dispute cases (ICQ) of 6.12 and the average of the RC ratio of 1.92% are as follows.

First, 34 numbers of QMIs, such as *A*8, *A*9, and *A*10, marked with gray circles, belong to the *S-L* area located at the lower left of Figure 12. The sum of the repair costs for each QMI in the *S-L* area is about 6.29%, which is lower than in other areas. Also, in the *S-L* area, the number of dispute cases (ICQ) and the repair cost ratio (RC ratio) are lower than the average. Therefore, it does not occur often, and even if it does, the damage seems insignificant.

Second, seven QMIs, *A*2, *A*4, and *A*5, marked with yellow circles, belong to the *F-L* area located at the lower right of Figure 12. The sum of the repair costs for each QMI

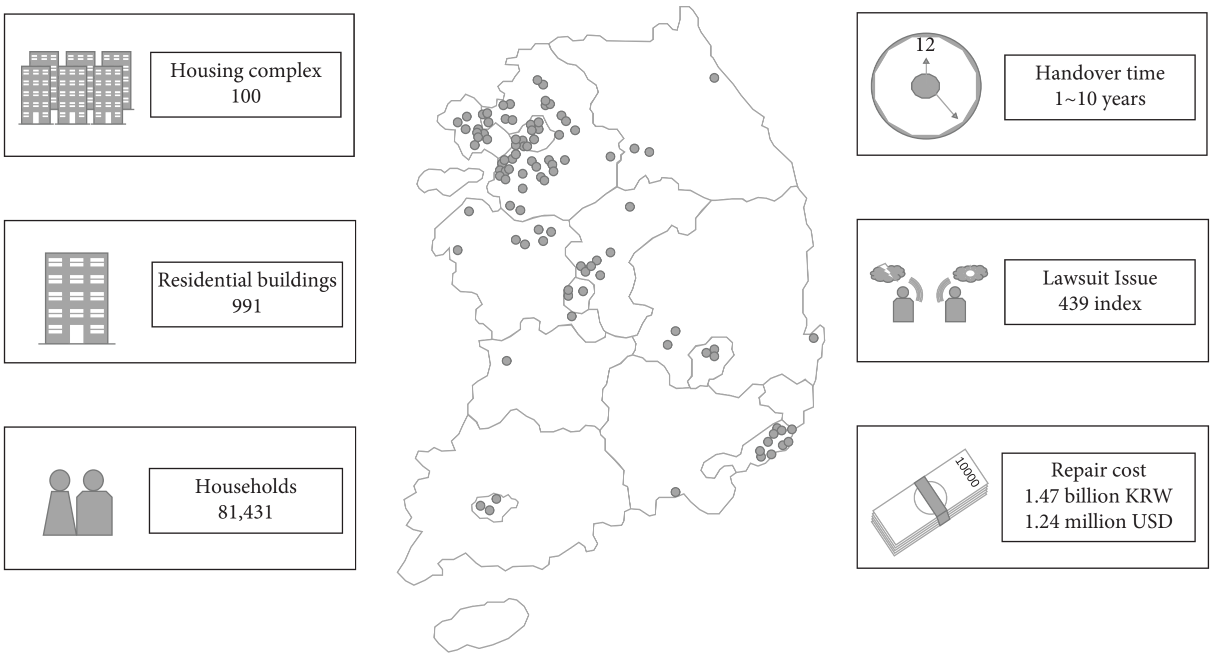


FIGURE 3: Case status.

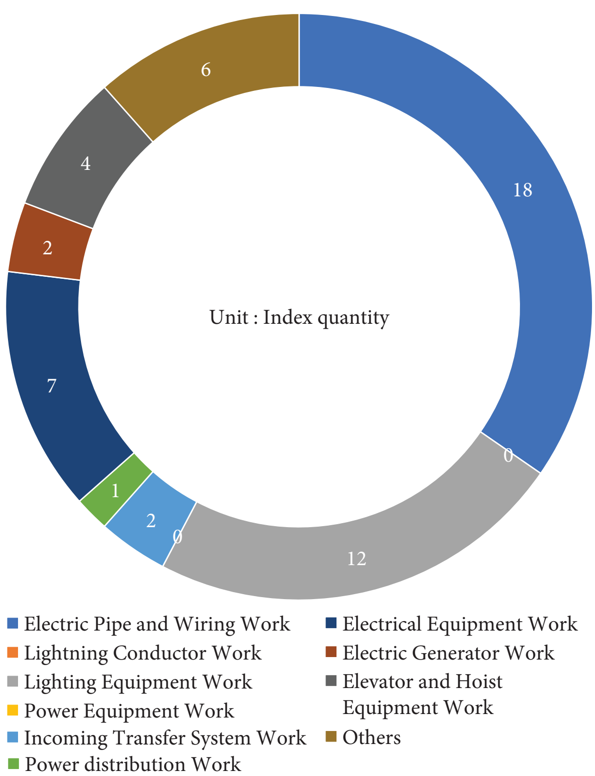


FIGURE 4: Distribution on detailed work.

in the *F-L* area is about 5.55% of the total. This figure is lower than the *S-L* area, but since the number of QMIs in the *F-L* area is significantly smaller than that in the *S-L* area, it is difficult to ascertain that the weightage of repair costs is low. Meanwhile, although the *F-L* area occurs frequently, the damage seems small.

Third, *A*7, *A*18, and *A*44, marked with a red triangle, belong to the *S-H* area located at the upper left of Figure 12. The sum of the QMI repair costs in the *S-H* area is about 28.3%. Although the *S-H* area has only three QMIs, the repair cost is higher than that of the *S-L* and *F-L* combined. Although the frequency of occurrence of these defects is minor, the repair costs are high if they occur, so they potentially cause much damage.

Fourth, eight QMIs, such as *A*1, *A*3, and *A*14, marked with blue rectangles, belong to the *F-H* area located at the upper right in Figure 12. When all the QMI repair costs in the *F-H* area are summed up, they account for 59.86% of the total. These seem to occur frequently and take high repair costs.

Combining the results of comparing the number of dispute cases and the repair cost ratio for the QMI of Index *A* above, the *S-L* area or *F-L* area, which has a relatively low frequency of quality problems and low repair costs, has many QMIs but takes low repair costs. The total repair cost of QMIs belonging to these two areas is only 11.84%, but the number of QMIs is 41, which is 78.8% of the total. Therefore, this does not conform to the Pareto composition that intends to select a vital quality management index. As for QMIs in the *F-H* area, where quality problems frequently occur and repair costs are also high, and in the *S-H* area, where the defect occurrence frequency is low but high, repair costs are 11 or 21.2% of the total.

It is considered reasonable to regard it as a valuable index candidate. Therefore, this study selected 11 QMIs in the *F-H* and *S-H* areas under Index *E*.

*4.7. Comparison.* To compare the quality management system of electric housing works and derive the critical index, the previous indices were compared with each other.

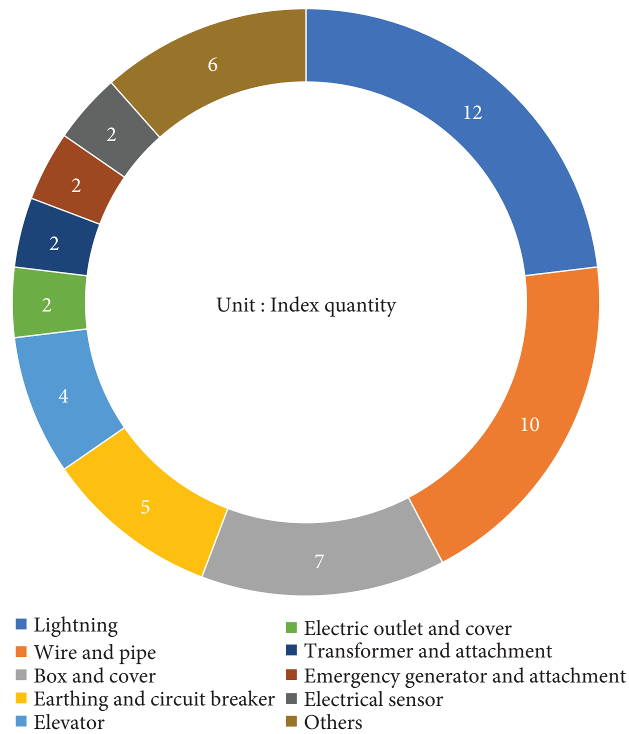


Figure 5: Distribution on object.

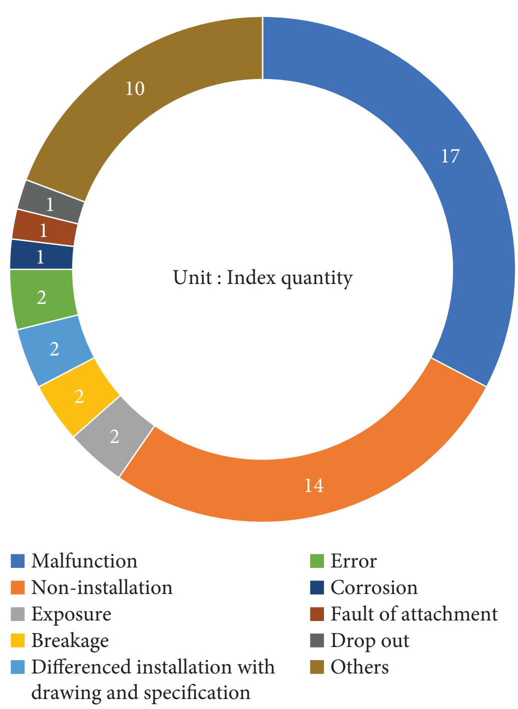


Figure 6: Distribution on phenomena.

Figure 13 shows the subindex and repair cost ratio of each index. Since the Index *A* included all detailed indices of electric housing work derived through case analysis, the detailed index and repair cost ratios of Index *A* were 100%, respectively.

In Index *B*, as shown in Figure 13, the subindex ratio was 5.77%, and the repair cost ratio was 24.14%. Index *B* had the lowest subindex ratio among the indices to be compared and the lowest repair cost ratio. The Pareto Principle stated that 80% of all outcomes came from 20% of all factors. However, since the ratio of the detailed indices of Index *B* was 5.77%, it was within 20% of the total factors according to the Pareto rule. However, since the repair cost ratio was only 24.14%, it was far below the result of the Pareto law of 80%.

In Index *C*, the subindex ratio was 11.54%, and the repair cost ratio was 34.09%, as shown in Figure 13. The subindex ratio of Index *C* was about twice that of Index *B*, but it was within 20% of the Pareto law factor. Moreover, Index *C* had a 10% higher repair cost than Index *B*. However, it seemed to fall short of the 80% result of the Pareto Principle.

In Index *D*, as shown in Figure 13, the subindex ratio was 55.77%, and the repair cost ratio was 68.66%. Since the repair cost ratio of Index *D* was 68.66%, it was about 2-3 times higher than Index *B* or Index *C*, which was noticeably high. However, it did not conform to the result of the Pareto principle of 80%. In addition, the subindex ratio of Index *D* far exceeded the 20% factor of the Pareto principle. Therefore, selecting all the QMIs in Index *D* as essential indices for the quality management system for housing electrical works is difficult.

In Index *E*, it can be seen from Figure 13 that the detailed index ratio was 21.15%, and the repair cost ratio was 88.16%. The subindex ratio of Index *E* was 21.15%, which was 20% of the factor of Pareto's law. Since Index *E*'s repair cost ratio was 88.16%, it was more than 80%, resulting from Pareto's law. Therefore, Index *E* could be regarded as a system that conformed to Pareto's law, as the subindex ratio was 20% of

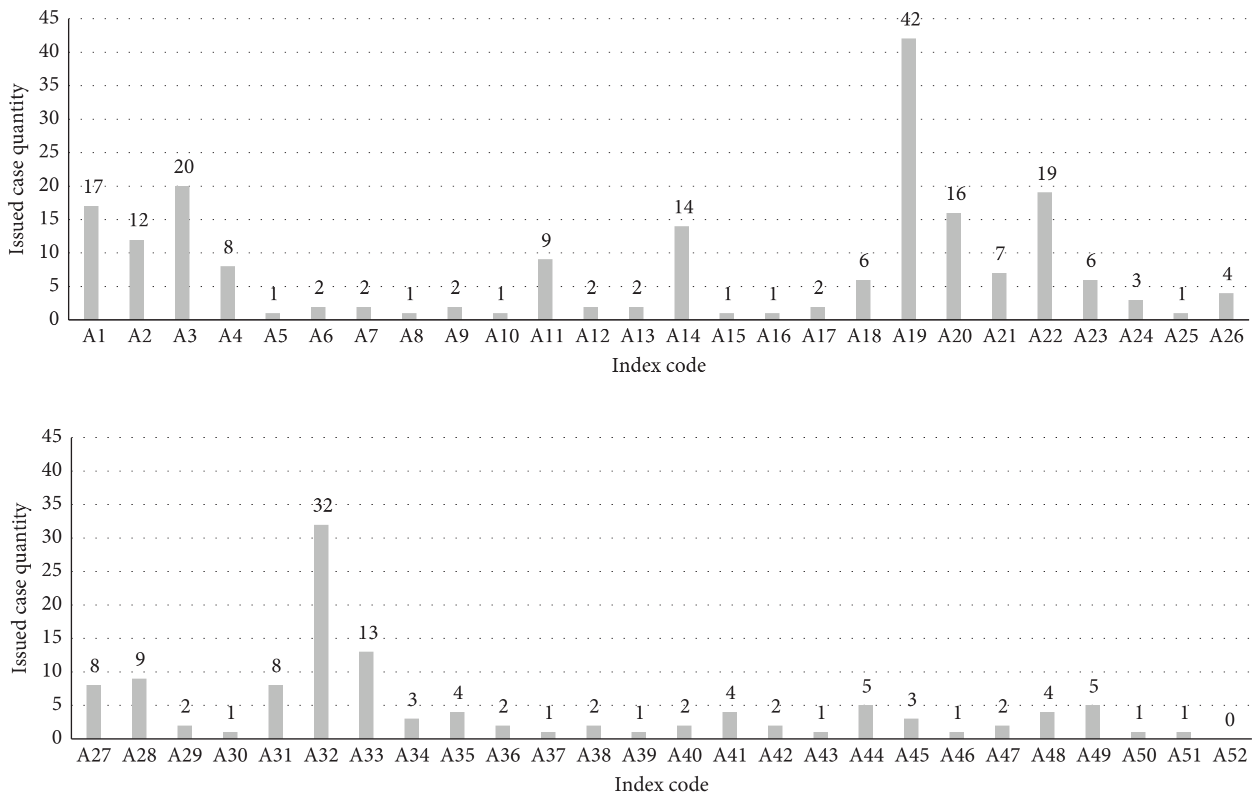


Figure 7: Issued case quantities of index *A*.

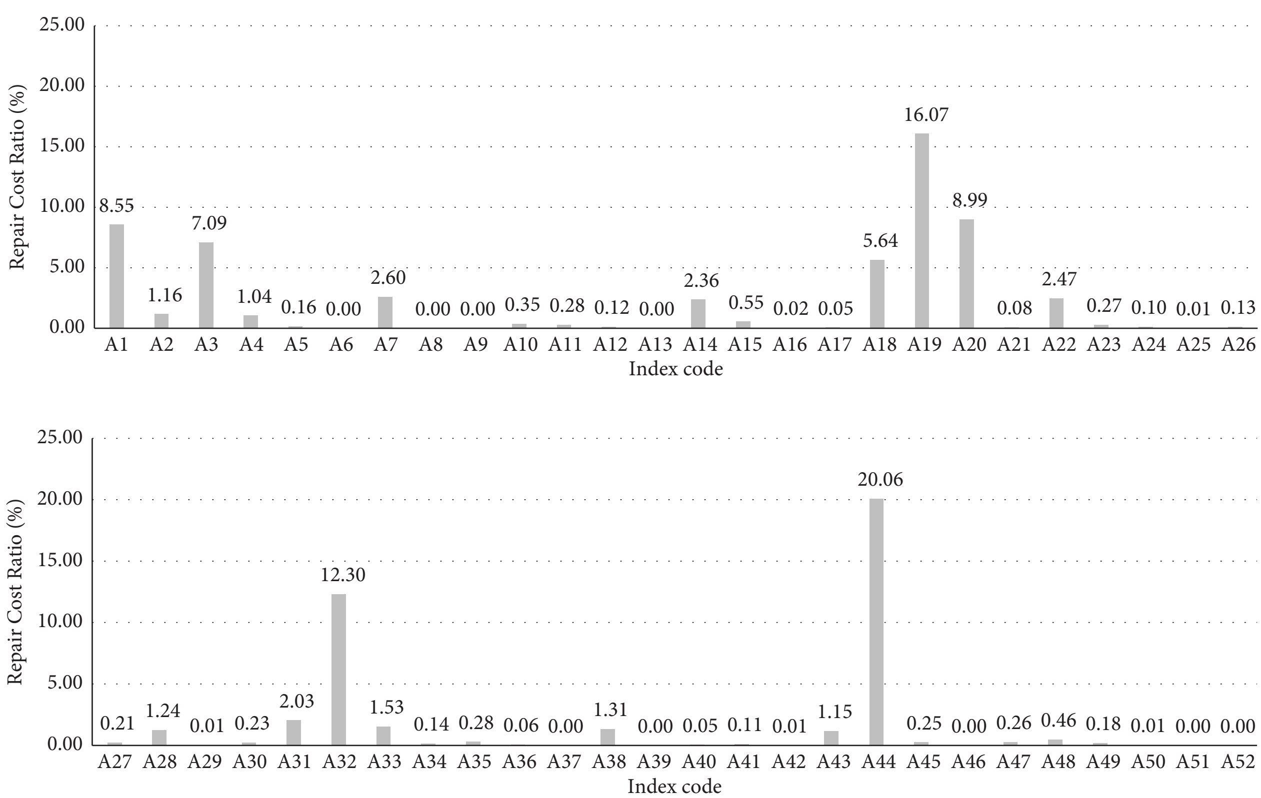


Figure 8: Repair cost ratio of index *A*.

Table 3: Quality management item of index *B*.

| Code | Object | Phenomena | | Similar item within index *A* |
|---|---|---|---|---|
| | | In regulation | Others | |
| *B*1 | Flexible wireway in bathroom ceiling | | Non-installation | *A*1 |
| *B*2 | Built-in home appliance | Malfunction | | *A*52 |
| *B*3 | Lighting and lamp ballast | Malfunction | | *A*19 |

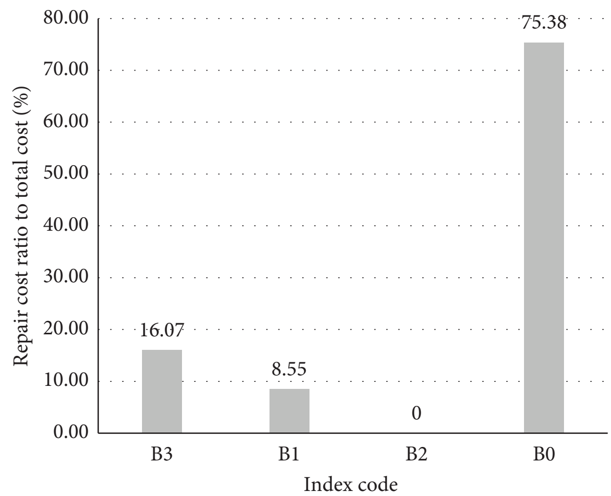


Figure 9: Pareto graph on repair cost of index *B*.

Table 4: Quality management item of index *C*.

| Code | Object | Phenomena | | Similar item within index *A* |
|---|---|---|---|---|
| | | In regulation | Others | |
| *C*1 | Flexible wireway in bathroom ceiling | | Non-installation | *A*1 |
| *C*2 | Lighting | Malfunction | | *A*19 |
| *C*3 | Lighting | Fault of attachment, electrical earthing, and cross connection | | *A*34 |
| *C*4 | Lighting | | Mismatch with drawing | *A*20 |
| *C*5 | Lighting | | Drop out | *A*27 |
| *C*6 | Lighting | | No lit | *A*26 |

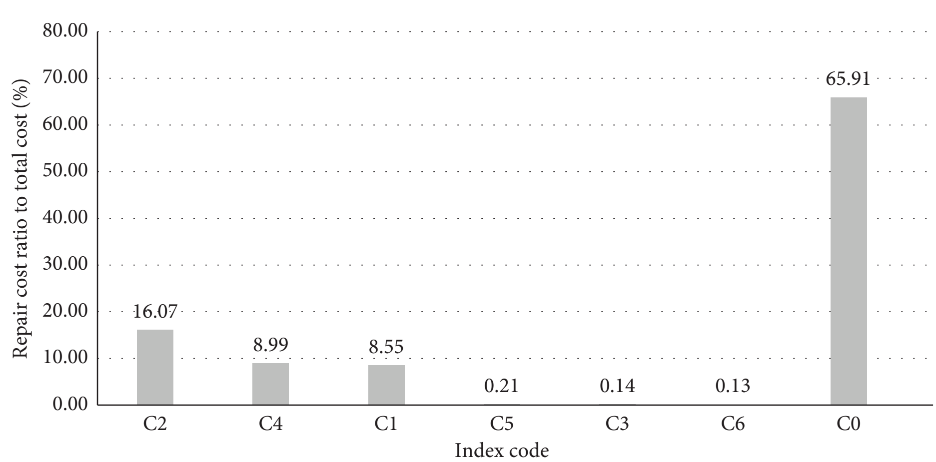


Figure 10: Pareto graph on repair cost of index *C*.

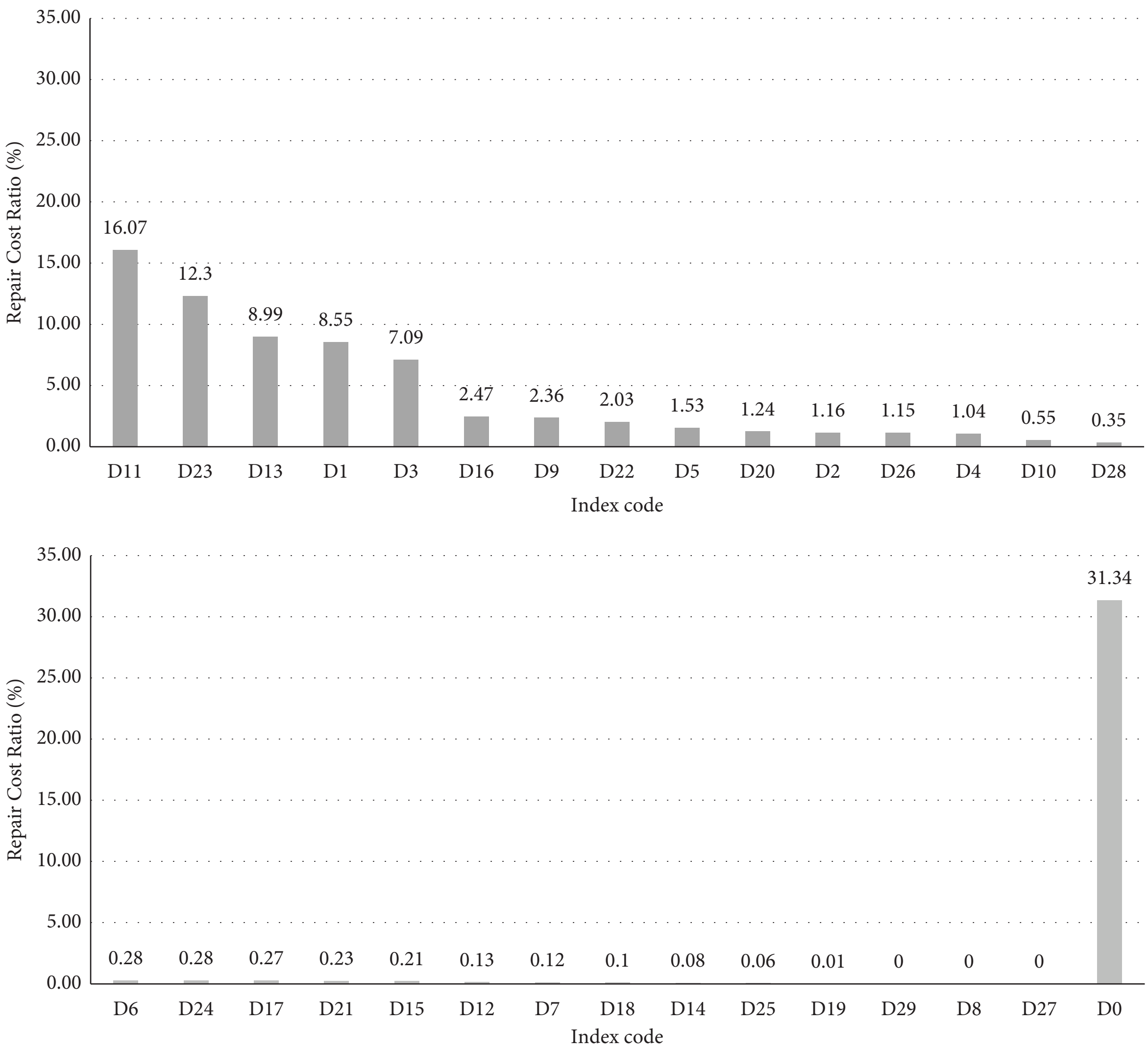


Figure 11: Pareto graph on repair cost of index *D*.

the total and the repair cost ratio was more than 80% of the total. Considering these points, Index *E* was considered an important index representing the quality system of electric housing works.

## 5. Discussion

As discussed earlier, this study proposed a quality management index (QMI) that could identify the general quality problems in the housing electrical work after the house was handed over to the owner. In addition, using two comparison scales of the quality management index, the number of cases of quality problems (ICQ) and the repair cost ratio (RC ratio), a method for setting management goals for quality problem improvement was proposed. Based on these research results, what improvements could be drawn compared to the past and what they suggest will be discussed in this chapter.

*5.1. Quality Management Index and Prime Index of Housing Electrical Work.* Housing electricity is vital in terms of functionality and safety for residents' lives. However, most previous studies focused on the overall housing quality problem, and housing electrical work was rarely discussed. Nonetheless, according to the results of the previous case studies, various quality problems occurred in the post-handover stage of housing electrical work, and the amount of quality problems generated and the cost to repair them were also significant. Through this study, along with the opinions of some previous studies, it was possible to confirm that the quality problem of housing electrical works exists and is also important.

Regarding the quality problems in housing electrical works, related standards and previous studies also suggested some types. However, most of them focused on fields other than electrical work, so they could not describe it in detail. On the other hand, Kim et al. [51] and Park et al. [52]

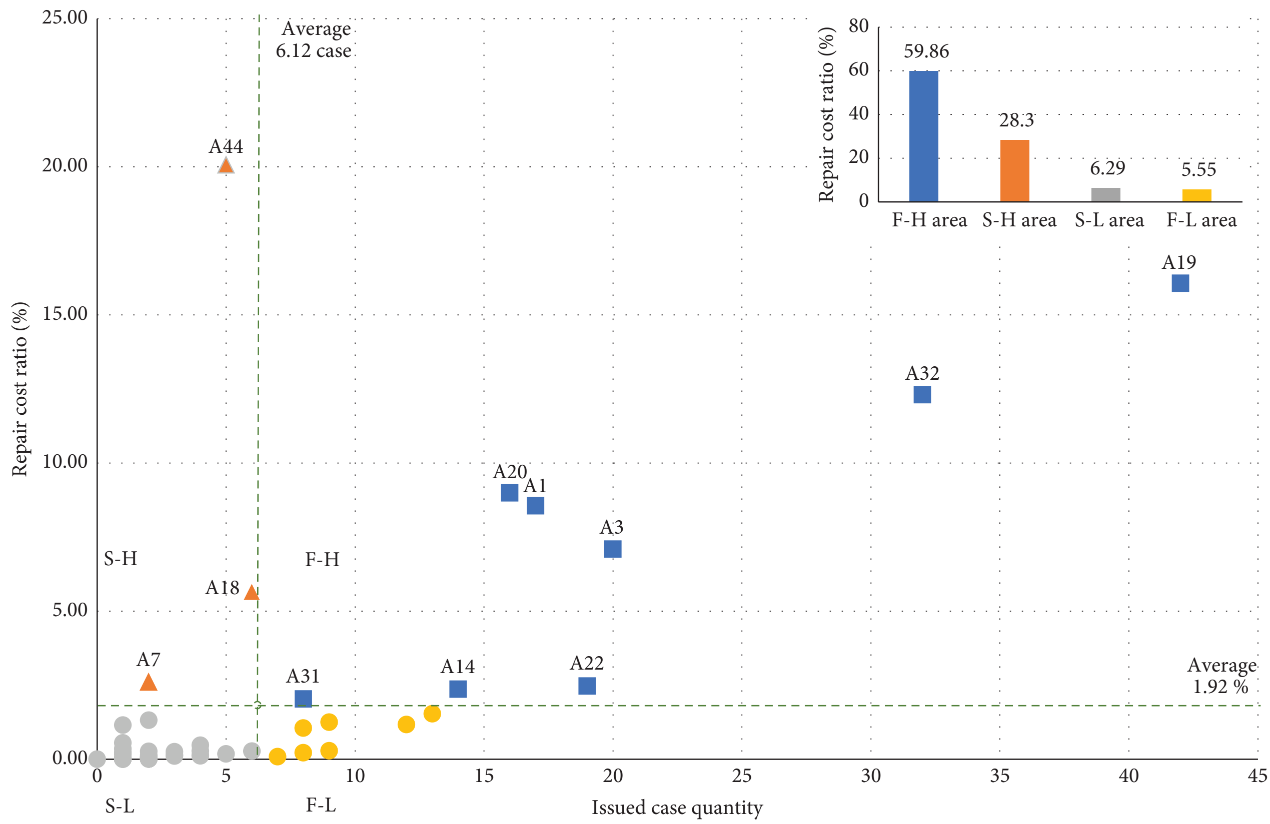


Figure 12: Comparison between issued case quantities and repair cost ratio.

focused on the quality problem of housing electrical works and presented detailed defect types. This study went one step further than these studies on the quality problems of housing electrical works. A quality management index that was specifically and systematically classified according to detailed work, object, and type was presented.

In the previous study, the number of defects, number of cases, and repair cost were used as indices to determine how significant the quality problem of housing electrical works was. However, the previous studies interpreted these indices as they were and could not establish new standards by applying them or suggesting specific ways to use them. On the other hand, this study adopted the number of cases and repair cost among the indices suggested in the previous studies and combined them to understand the overall quality of the housing electrical work. In addition, a method for comparing the quality management index was presented. The comparison results showed that a critical index representing the quality problem of the housing electrical works could be developed to the suggested level.

On the other hand, if the index is to function as an essential index of the housing electrical work, it should be able to represent the overall quality problem sufficiently. However, the previous studies did not specifically reveal how much their research results could represent the quality problem of housing electrical works. Accordingly, based on the case data collected in this study, a comparison was made to select a better index among the quality management indices of the previous studies and major indices of this study that can represent the quality problem of housing electrical works. As a result of comparison based on the total repair cost, the previous study accounted for 5.77% of the total repair cost at the lowest and 55.77% in the highest case. This does not conform, however, to the Pareto principle, a representative quality control method, and does not conform to the long tail rule, which is the opposite case. In addition, no specific quality management method was suggested in the previous studies, and even if the analysis results were followed, it seems complicated to relate them to other quality management methods. On the other hand, in the important index suggested in this study, 80% of the result was caused by a 20% level of the cause, confirming that it was following the typical Pareto principle. Therefore, it is considered that this study's important index not only represents the quality problem of housing electrical works, but also applies the quality control strategy related to the Pareto principle.

*5.2. Improvement Plan to Quality Management.* As discussed above, since the important indices presented in this study tended to conform to the Pareto principle, it can be considered to apply the accompanying choice and concentration strategy to the quality management of housing electrical works. Therefore, a method to utilize the important index, as shown in Figure 14 below, is proposed, and it can be precisely divided into the two following stages (tracks).

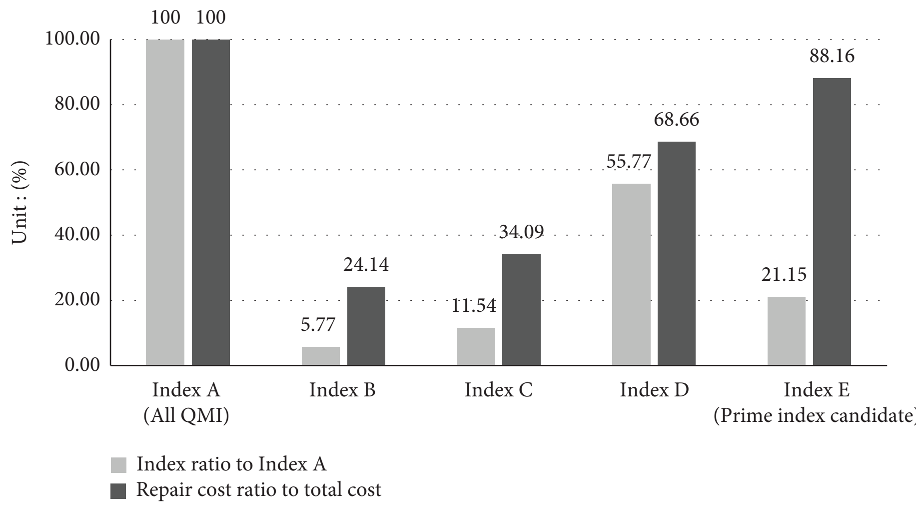


Figure 13: Pareto comparison on all indexes.

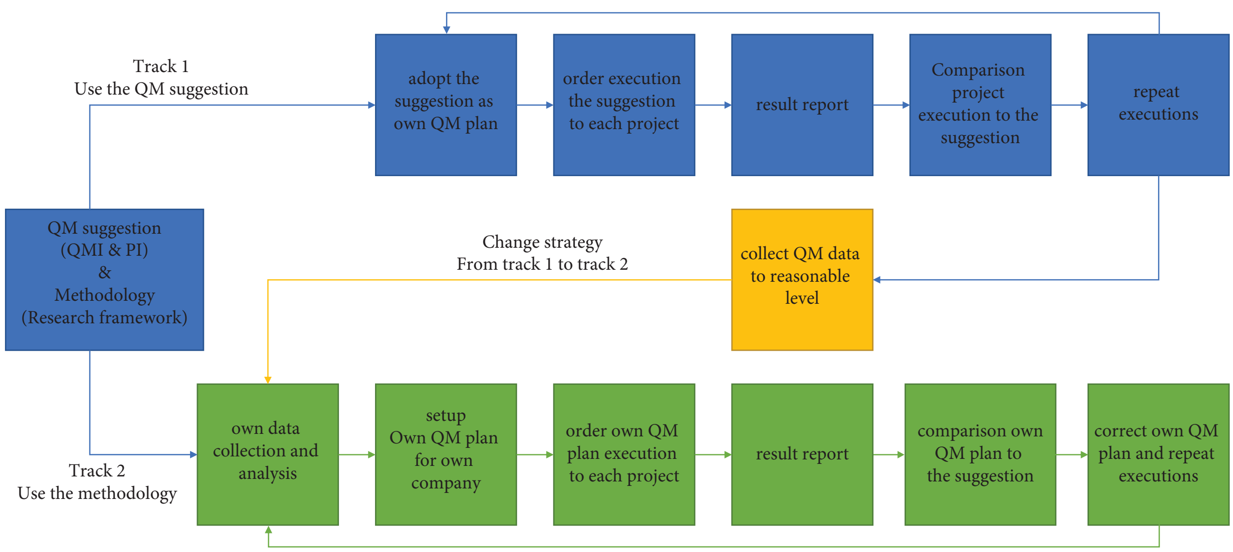


Figure 14: Quality management plan.

In the first stage (track 1), as shown in the upper part of Figure 14, the quality management index and important index, the quality management suggestions of this study, were adopted as such and set and managed as a quality management goal for each company or unit site. For the quality management of each company, it is desirable to establish an optimized quality management measure by identifying the company's status according to the procedure outlined in the framework of this study. However, if the company size is small or there are not many projects to be carried out, it is difficult for an inexperienced manager to establish a basis for setting quality management goals. Therefore, this study's quality management index and important quality index can be a suitable strategy for start-ups or small businesses in the housing business. Since the important index of this study was selected based on the analysis of numerous cases, it can be regarded as fully reflecting the business conditions, so the important index, the result of this study, can be set as an explicit management goal. It is desirable to repeat the process until a suitable number of cases are accumulated and then switch to the second stage below.

The second stage (track 2) explains where each company establishes and operates its quality management plan according to the framework presented in this research method, as shown at the bottom of Figure 14. If a company carries out enough projects and there are many managers with various experiences, a quality management plan can be established based on the results of collecting their case data and analyzing them using the method of this study. The head office can draw up a quality management index at the company-wide level, derive an essential index, and then apply it to each site to serve as a driving force to strengthen quality management. In addition, each site can optimize quality management by modifying the management goal and comparing the critical index suffered by the head office with the site's conditions. The quality control results of these sites are sent back to the head office so that the entire company's quality management level can be checked and compared between sites. In addition, lacking points and sites with poor performance are identified to seek focused improvement at the company-wide level. By repeating this stage, data can be continuously collected, and lessons from successes and failures can be accumulated to adjust the quality management measures.

## 6. Conclusions

In order to improve the quality of housing electrical works in the post-handover stage, a standard that can identify the overall problem must be prepared. In addition, a methodology that includes a quantitative scale for setting and comparing management goals is required. For this purpose, this study collected housing dispute case data and classified housing electrical work quality problems as a quality management index. Furthermore, as a comparison scale for each quality management index, a method of comparing the quality management indices was proposed using the number of dispute cases and the ratio of defect repair costs. In addition, a strategy was proposed to focus quality management capabilities on important indices that conform to the Pareto principle based on the repair cost. Although the construction entity must have delivered the house to the owner after judging that the house is complete and there are no problems, the analysis results of this study show that various quality problems occur in the post-handover stage. Therefore, construction entities should use the results of this study as an opportunity to make further efforts to prevent the occurrence of quality problems in the future. In addition, since the quality management index or important index of this study is an alternative based on problems that occur in housing electrical work, it is helpful in practical terms because it can be applied to on-site quality management as it is.

On the other hand, this study also has the following limitations. Depending on the design level and type of a house, the details of electrical work may vary, and the usage environment is different, so in some cases, important quality problems that no one expected may arise. In addition, as social issues such as energy saving and carbon reduction are raised, various regulations are being added during house construction. In the case of housing electrical work, the introduction of energy-saving lighting devices is becoming mandatory. Even solid-state lighting, a representative energy-saving lighting device, has a shorter life span than expected, and various problems are reported from the beginning. Therefore, there is a limit to responding to all quality problems only with the quality management index or important index of the housing electrical work for currently constructed houses. In the future, it is necessary to exchange information on new quality issues and discuss technical supplementation methods according to the business environment and technological changes.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there is no conflicts of interest regarding the publication of this paper.

## Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) Grant Funded by the Korea Government (2019R1A2C1009913).

## References

[1] R. N. Milion, T. d. C. Alves, and J. C. Paliari, "Impacts of residential construction defects on customer satisfaction," *International Journal of Building Pathology and Adaptation*, vol. 35, no. 3, pp. 218–232, 2017.

[2] A. Aaker, *Building Strong Brands*, Free Press, New York, 1996.

[3] R. P. Morgan, "A consumer-oriented framework of brand equity and loyalty," *International Journal of Market Research*, vol. 42, no. 1, pp. 1–9, 2000.

[4] B. Yoo, N. Donthu, and S. Lee, "An examination of selected marketing mix elements and brand equity," *Journal of the Academy of Marketing Science*, vol. 28, no. 2, pp. 195–211, 2000.

[5] P. Elton and J. Packer, "A prospective randomised trial of the value of rehousing on the grounds of mental ill-health," *Journal of Chronic Diseases*, vol. 39, no. 3, pp. 221–227, 1986.

[6] S. F. Suglia, C. S. Duarte, and M. T. Sandel, "Housing quality, housing instability, and maternal mental health," *Journal of Urban Health*, vol. 88, no. 6, pp. 1105–1116, 2011.

[7] H. Builders Federation, "National new home customer satisfaction survey," 2022, https://www.hbf.co.uk/documents/11636/17th_Survey_CSS_2022_Completions_October_2020_-_September_2021v3.pdf.

[8] H. Owners Alliance, "Homeowner survey 2019: top UK housing concerns revealed," 2019, https://hoa.org.uk/2019/08/homeowner-survey-2019.

[9] National Customer Satisfaction Index, "Customer satisfaction index of apartment construction firm," 2022, https://ncsi.or.kr/score/company.asp?sector=N04&industry=N0401&sYear=2011&eYear=2021.

[10] Apartment Defect Dispute Mediation Committee, "Defect management information system," 2022, https://www.adc.go.kr.

[11] A. Elmualim and J. Gilder, "BIM: innovation in design management, influence and challenges of implementation," *Architectural Engineering and Design Management*, vol. 10, no. 3-4, pp. 183–199, 2014.

[12] P. E. Love, Z. Irani, E. Cheng, and H. Li, "A model for supporting inter-organizational relations in the supply chain," *Engineering Construction and Architectural Management*, vol. 9, no. 1, pp. 2–15, 2002.

[13] M. Suprapto, H. L. Bakker, H. G. Mooi, and W. Moree, "Sorting out the essence of owner–contractor collaboration in capital project delivery," *International Journal of Project Management*, vol. 33, no. 3, pp. 664–683, 2015.

[14] B. Torregrosa-Jaime, P. J. Martínez, B. González, and G. Payá-Ballester, "Modelling of a variable refrigerant flow system in energy plus for building energy simulation in an open building information modelling environment," *Energies*, vol. 12, no. 1, p. 22, 2018.

[15] A. T. Gurmu, A. Krezel, and C. Ongkowijoyo, "Fuzzy-stochastic model to assess defects in low-rise residential

buildings," *Journal of Building Engineering*, vol. 40, Article ID 102318, 2021.
[16] Y. Kim and K. You, "The study to environmental factors using microclimate survey of traditional wooden Silsang Temple in Korea," *Environmental Monitoring and Assessment*, vol. 190, no. 11, p. 630, 2018.
[17] S. Carson, "Toxic mold: latest construction defect", journal of professional issues in engineering education and practice," *American Society of Civil Engineers*, vol. 129, no. 3, pp. 171–176, 2003.
[18] N. Novita, H. Amiruddin, H. Ibrahim et al., "Investigation of termite attack on cultural heritage buildings: a case study in aceh province, Indonesia," *Insects*, vol. 11, no. 6, p. 385, 2020.
[19] A. Colombo, L. Oldani, and S. Trasatti, "Corrosion failure analysis of galvanized steel pipes in a closed water cooling system," *Engineering Failure Analysis*, vol. 84, pp. 46–58, 2018.
[20] J. Park and D. Seo, "Construction defect and maintenance problem of watering apparatus and sanitary work in apartment building," *International Journal of Advanced Science and Technology*, vol. 29, no. 4, pp. 949–961, 2020.
[21] S. Bobba, F. Ardente, and F. Mathieux, "Environmental and economic assessment of durability of energy-using products: method and application to a case-study vacuum cleaner," *Journal of Cleaner Production*, vol. 137, pp. 762–776, 2016.
[22] S. Lee, "Analysis on the use of household appliances power," Master Thesis, Gachon University, Seongnam, South Korea, 2013.
[23] M. Park, "Analysis of seasonal power usage patterns of apartment, public office, university and university hospital," Master Thesis, Pusan National University, Pusan, South Korea, 2013.
[24] V. Hutchison, "Residential electrical fire problem: the data landscape," 2018, https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Electrical/RFResidentialElectricalFireData.pdf.
[25] K. S. Jeong, Y. S. Kim, C. M. Kim, and O. M. Kwon, "Statistical life estimation according to dielectric breakdown test of aged IV wires," *The Transactions of the Korean Institute of Electrical Engineers*, vol. 69, no. 4, pp. 623–628, 2020.
[26] O. M. Machidon, C. Stanca, P. Ogrutan, C. Gerigan, and L. Aciu, "Power-system protection device with IoT based support for integration in smart environments," *PLoS One*, vol. 13, Article ID e0208168, 2018.
[27] B. Bridge, D. Adhikari, and M. Fontenla, "Electricity, income, and quality of life," *The Social Science Journal*, vol. 53, no. 1, pp. 33–39, 2016.
[28] J. Scarcelli and D. Nelson, "Loss of electricity and refrigerated foods: avoiding the danger zone," *FIU Hospitality Review*, vol. 31, no. 2, pp. 55–65, 2013.
[29] U.S. Fire Administration, "U.S. fire statistics," 2022, https://www.usfa.fema.gov/data/statistics/#what.
[30] Home Office, "Detailed analysis of fires attended by fire and rescue services," 2020, https://www.gov.uk/government/statistics/detailed-analysis-of-fires-attended-by-fire-and-rescue-services-england-april-2020-to-march-2021/detailed-analysis-of-fires-attended-by-fire-and-rescue-services-england-april-2020-to-march-2021.
[31] National Fire Agency, "National fire agency statistical year book," 2021, https://www.nfa.go.kr/nfa/releaseinformation/statisticalinformation/main/?boardId=bbs_0000000000000019&mode=view&cntId=36&category=&pageIdx=&searchCondition=&searchKeyword=.
[32] P. M. Randall, "Mercury reduction in products and processes: a review of the electrical and electronic industries," *Environmental Progress*, vol. 14, no. 4, pp. 232–239, 1995.
[33] A. Kroupa, D. Andersson, N. Hoo et al., "Current problems and possible solutions in high-temperature lead-free soldering," *Journal of Materials Engineering and Performance*, vol. 21, no. 5, pp. 629–637, 2012.
[34] C. Chaine, A. S. Hursthouse, B. McLean et al., "Recycling plastics from weee: a review of the environmental and human health challenges associated with brominated flame retardants," *International Journal of Environmental Research and Public Health*, vol. 19, no. 2, p. 766, 2022.
[35] European Commission, "Waste from electrical and electronic equipment (WEEE)," 2022, https://ec.europa.eu/environment/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en.
[36] M. Conti and S. Orcioni, "Modeling of failure probability for reliability and component reuse of electric and electronic equipment," *Energies*, vol. 13, no. 11, p. 2843, 2020.
[37] D. D. Shipp, T. J. Dionise, V. Lorch, and B. G. MacFarlane, "Transformer failure due to circuit-breaker-induced switching transients," *IEEE Transactions on Industry Applications*, vol. 47, no. 2, pp. 707–718, 2011.
[38] P. Lall, P. Sakalaukus, and L. Davis, "Reliability and failure modes of solid-state lighting electrical drivers subjected to accelerated aging," *IEEE Access*, vol. 3, pp. 531–542, 2015.
[39] M. Hwang, M. Lee, J. Lee, D. Shin, Y. Kim, and J. Kim, "Analysis of construction problems about HFIX and study of improvement method on electric wire and cable in low voltage electric equipment of integrated test-site based on IEC 60364," *Journal of the Korean Institute of Illuminating and Electrical Installation Engineers*, vol. 30, no. 9, pp. 56–63, 2016.
[40] J. Lee, "A study on the reduction of elevator failure by season," Master Thesis, Seoul National University of Science and Technology, Seoul: South Korea, 2017.
[41] Society for Construction Lawsuit and Society for Construction Lawsuit, "Seoul central District court. Construction appraisal practice," *Society for Construction Lawsuit in Seoul central District Court, Seoul: South Korea*, Korean, 2016.
[42] National Law Information Center, "A judged standard, investigated method and estimated costing of defect in dwelling house, South Korea," 2016, https://www.law.go.kr/admRulSc.do?menuId=5&query=%ED%95%98%EC%9E%90%ED%8C%90%EC%A0%95#liBgcolor0.
[43] J. Georgiou, J. Smith, and P. E. D. Love, "A benchmark study on housing defects in victoria, Australia," *International Journal of Construction Management*, vol. 4, no. 2, pp. 89–100, 2004.
[44] J. Lee, "A study on the defect reduction method through analyzing the defects pattern of apartment - with the point of cost," Master Thesis, Catholic Kwandong University Korean, Gangneung: South Korea, 2010.
[45] M. Yu, "The study on the causes of defect & reduction measure of the apartment house," Master Thesis, Daegu University Korean, Daegu: South Korea, 2011.
[46] N. Forcada, M. Macarulla, M. Gangolells, and M. Casals, "Handover defects: comparison of construction and post-handover housing defects," *Building Research & Information*, vol. 44, no. 3, pp. 279–288, 2015.
[47] J. Choi, *Evaluation of Defect Repairing Bond Ratio through Defect Lawsuit Case Study in Apartment Building*, Ph.D Dissertation, Chungbuk National University Korean, Cheongju: South Korea, 2017.

[48] P. E. D. Love, P. Teo, and J. Morrison, "Revisiting quality failure costs in construction," *Journal of Construction Engineering and Management*, vol. 144, no. 2, Article ID 05017020, 2018.
[49] E. Chisholm, M. Keall, J. Bennett et al., "Why don't owners improve their homes? Results from a survey following a housing warrant-of fitness assessment for health and safety," *Australian & New Zealand Journal of Public Health*, vol. 43, no. 3, pp. 221–227, 2019.
[50] A. Hyder Chohan, J. Awad, C. Jung, and A. Irfan Che Ani, "Development of smart application for house condition survey," *Ain Shams Engineering Journal*, vol. 13, no. 3, Article ID 101628, 2022.
[51] J. Kim, C. Song, and Y. Kim, "Defect analysis and reduction measures of apartment electric equipment," *Journal of the Architectural Institute of Korea(Structure & Construction)*, vol. 10, no. 3, pp. 265–272, 2008.
[52] J. Park, J. Seo, S. Um, and C. Kim, "Defect types of electrical work in house construction," *Solid State Technology*, vol. 63, no. 5, pp. 6428–6443, 2020.
[53] J. Park and D. Seo, "Defect index of timberwork in house, Korea," *Forests*, vol. 12, no. 7, p. 896, 2021.
[54] B. Kim, J. Park, J. Choi, D. Seo, and O. Kim, "Comparative analysis on repairing cost of lawsuit on concrete crack defect in apartment building," *Korea Journal of Construction Engineering and Management*, vol. 12, no. 6, pp. 142–150, 2011.
[55] J. Seo, *Model for predicting the occurrence of defects in high-rise residential building*, Ph.D Dissertation, Korea University Korean, Seoul: South Korea, 2009.
[56] J. Park and D. Seo, "Basic study on term of warranty liability for water supply, drainage, and sanitation arrangement work defect in apartment building," *IOP Conference Series: Materials Science and Engineering*, vol. 216, Article ID 12055, 2017.
[57] D. Seo and J. Park, "Comparative analysis on landscape work defect types in apartment buildings through defect dispute case," *Asia Life Sciences*, vol. 15, no. 3, pp. 1719–1730, 2018.
[58] Korea Ministry of Government Legislation, "Korea Ministry of government legislation enforcement decree of the housing Act. Korean law information center," 2022, https://www.law.go.kr/LSW/eng/engLsSc.do?menuId=2&section=lawNm&query=housing+act&x=0&y=0#liBgcolor20.
[59] Korea Ministry of Government Legislation, "Korea Ministry of government legislation enforcement decree of the Act on house construction standard. Korean law information center," 2022, https://www.law.go.kr/admRulSc.do?menuId=5&subMenuId=41&tabMenuId=183&query=%EC%A3%BC%ED%83%9D%EC%9D%98%20%EC%84%A4%EA%B3%84%EB%8F%84%EC%84%9C%20%EC%9E%91%EC%84%B1%EA%B8%B0%EC%A4%80#liBgcolor0.
[60] D. S. Seo and J. M. Park, "Analysis of consulting reports on defect disputes in apartment building," *Journal of the Korea Institute of Building Construction*, vol. 13, no. 5, pp. 498–505, 2013.
[61] J. Choi, J. Park, D. Seo, J. Jo, K. Park, and O. Kim, "A Study on legal issues about defect repair claim on apartment building," *Journal of Architectural Institute of Korea*, vol. 25, no. 11, pp. 145–153, 2009.
[62] Bank of Korea, "Economics statistics system," 2022, https://ecos.bok.or.kr.
[63] Y. S. Chen, P. Chong, and M. Tong, "Mathematical and computer modelling of the Pareto principle," *Mathematical and Computer Modelling*, vol. 19, no. 9, pp. 61–80, 1994.
[64] F. Lopez, C. D. Bartolo, T. Piazza et al., "A quality risk management model approach for cell therapy manufacturing," *Risk Analysis*, vol. 30, pp. 1857–1871, 2010.
[65] E. Brynjolfsson, Y. J. Hu, and D. Simester, "Goodbye Pareto principle, hello long tail: the effect of search costs on the concentration of product sales," *Management Science*, vol. 57, no. 8, pp. 1373–1386, 2011.
[66] O. Hinz, J. Eckert, and B. Skiera, "Drivers of the long tail phenomenon: an empirical analysis," *Journal of Management Information Systems*, vol. 27, no. 4, pp. 43–70, 2011.