Design, Construction, and Curing Integrated Management of Defects in Finishing Works of Apartment Buildings

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Abstract: The site analysis performed in the last ten years has found that building defects result from inconsistent decision-making and performance in the design, construction, and curing (DCC) processes. Therefore, for sustainable quality control, DCC integrated analysis and the management of causes by type and response measures should be in place. The objective of this study is to propose DCC integrated management of defects in finishing works of apartment buildings. To this end, the study surveyed 69,944 defects from 3299 apartment households and analyzed the defect types and causes by project stage. As a result, in the case of opening work (WT1), opening and closing (DT1) accounted for the highest proportion at 35.7%. In the case of furnishing work (WT2), floor installation (DT1) has the most defects. Moreover, the proposed integrated defect management technique was applied onsite, which resulted in an improvement where the defect frequency decreased by 56.80%. The results of this study will be used as the basic data for high-quality finishing projects, and the proposed management concept can be used as reference data in the establishment of a defect management system.

Keywords: finishing work; defect management; apartment building; design; construction

1. Introduction

Defects in an apartment building degrade the living quality of residents and cause all stakeholders who participated in the construction project a substantial economic loss [1–5]. In particular, the occurrence of defects in finishing the construction of apartment buildings is inevitable owing to the use of various materials and components [6]. Jang [2] reported that the defects of an apartment building can be seriously damaging to stakeholders due to lots of costs for maintenance and repair. Therefore, effective quality management is needed to prevent the defects of apartment buildings. Lee et al. [6] also stated that resource wasting can occur and economic losses to the buildings, as well as mental and physical problems can be given to the residents. In this respect, these studies suggested that a targeted priority management selection according to the defect types is needed because the frequency, repair, and replacement costs are different according to the work classification.

In the case of defects, in addition to the deterioration of the building quality and monetary loss, a lot of embodied CO₂ emission occurs during the repair and replacement process. The reason is that when a defect occurs, not only the defective part is repaired, but the related parts are frequently repaired and replaced. For example, when a waterproof defect occurs, not only waterproofing, but also related finishes such as plastering mortar and paint must be repaired and replaced. Therefore, reducing defects by systematic management is very important from the perspective of sustainability.

To ensure high-quality finish works in a construction project, defects should be reviewed continuously, a systematic analysis should be conducted, and the results should
be reflected in the following projects so that no similar defects are repeated. However, there are no measures or management tasks being performed onsite to fundamentally prevent defects from recurring, and simply supplementary services against the identified defects are offered [7].

Lee, Lee, and Kim [7] investigated the loss from defects, focusing on apartment buildings, and suggested the priority of the defect type. However, their scope was limited to the defects of the construction phase and only focused on the management priority regarding the defects type. In other words, the prevention method and improvements were not suggested. Suffian [8] analyzed the defect of buildings in Malaysia and discussed general issues, such as the waterproofing system and cracks. However, this study did not suggest a fundamental prevention method after listing the factors influencing maintenance and repair of buildings.

The site analysis performed in the last ten years has found that building defects result from the inconsistent decision-making and performance in the design, construction, and curing (DCC) processes [9]. While there have been several studies on defects [9–19], few have focused on the analysis and management of defects by integrating DCC.

For example, Mills, Love, and Williams [14] analyzed the characteristics and maintenance costs of each type of defect using defect data generated in Australian housing buildings. Osman et al. [15] used defect data from hospital buildings to analyze defects in four major building elements: ceilings, walls, floors, and roofs. Bakri and Mydin [17] analyzed defect types and causes using defect generation data. Dong et al. [18] constructed a system concept for a construction defect management using defect data from the design office. In addition, Park and Seo [19] analyzed the type of defect occurrence using litigation data related to apartment defects. Most of these studies only provide basic data on defect management by analyzing the types or causes of defects by individual types of work using defects occurrence data.

For sustainable quality management of finishing works, the causes by defect type and solutions must be categorized and analyzed by DCC and an integrated management must be in place. The objective of this study is the DCC integrated management of defects in finishing works of apartment buildings. The results of this study will be used as the basic data for high-quality finishing projects, and the proposed management concept can be used as reference data in the establishment of a defect management system.

2. Methodology

The progress of this study is as shown in Figure 1. First, previous studies were reviewed in a preliminary study to define the concept of a defect and determine the influential factors of the defect. Second, apartment finishing works were collected as data, and defect types were analyzed. In this study, 69,944 defects from 3299 households in five apartment complexes that were identified for one year and five months after moving in were analyzed. Third, using the surveyed data, the study conducted a DCC integrated analysis on the causes of defects and solutions with interior works as case studies. Fourth, the analysis results were applied to the proposed DCC integrated management as a case study, and solutions were established. Accordingly, a case project was selected, and a DCC integrated countermeasure plan was established. Later, the results were applied to case work trades, and its effect was verified.
3. Preliminary Study

3.1. Concept of Building Defects

Defect is a term used in various industries, including construction, referring to a case in which there are problems that a product does not satisfy a normal state expected by the law or customer [20–22]. According to the California Civil Code 896, defects in buildings are defined as cracks, collapse, problems in electrical wiring or lighting, problems in a piping system, insulation, and soundproofing, etc. [17]. For the types of building defects, structural defects concern the functional aspects of a building, affecting the structural stability due to the defects in key structural parts, such as columns, girders, and bearing walls [23,24]. Moreover, finish defects include poor sound and heat insulation performance, finish cracks, and warping of doors and windows, etc. [11,25].

In particular, in the case of apartment buildings, residents’ complaints over the building quality can also be considered defects [26]. According to the Ministry of Land, Infrastructure and Transport of Korea, the warranty period is defined by work trade, meaning that the one for structural defects is ten years, whereas that for thermal and moisture work is three years and that for waterproofing work is five years. [27–29]. In case of defects, additional repair and replacement cost for rework is incurred. In Sweden, repair and replacement cost is 4.4% of the production cost, and the time it takes for the repair and replacement work is up to 7% of the total work hours. Considering that the average margin in construction in Sweden is about 2%, the repair and replacement cost is very high [30].

In case of new houses in Victoria, Australia, about 4% of the total construction cost is used for repair and replacement cost [31], and the yearly repair and replacement cost in construction estimated by the Danish government is around 1.7 billion Euro, which corresponds to 10% of the total production cost [32]. Such high repair and replacement costs cause considerable economic damage to construction companies; therefore, a lot of government- and company-level efforts towards defect management are being made globally [33].

3.2. Causes of Building Defects

According to the previous studies on the causes of building defects, factors causing defects can largely be divided into DCC stages, as shown in Figure 2 [34–51]. As shown in Figure 2, causes of building defects are design errors, the selection of inappropriate materials and methods, no consideration of constructability, and insufficient design documents, etc. [34–40].

Causes of defects in the construction stage include the lack of material performance, poor supervision and inspection, omission of product parts, poor skill or workmanship, and noncompliance with specifications, etc. [41–46]. The causes of defects in the curing stage are poor temperature and humidity control, no curing material followed, damages caused by other work, and insufficient curing time, etc. [47,48]. The causes of defects in the maintenance stage are poor O&M, O&M errors or mistakes, no regular inspection, damage due to natural disasters, and careless use by residents, etc. [49–51].
From the viewpoint of construction projects, most defects are generated in the DCC stages, and this study verifies that the causes for many defects by work trade were through DCC integration. As shown in Figure 2, the causes of building defects have different characteristics in a product lifecycle.

**Figure 2. Causes of defects through the life cycle of buildings.**

However, factors such as a lack of integrated communication among project participants, lack of integrated project quality management, and frequent changes in orders of project owners are the causes of defects found in all stages. Among them, integrated communication and project quality management can be improved by DCC integrated management. For sustainable quality management in finishing works of apartment buildings, it is essential to conduct an integrated analysis while separating the causes of defects by work type into those in DCC stages.

Figure 3 is the integrated analysis concept of DCC in relation to the causes of defects. In Figure 3a, the defects in the design stage, in turn, cause the following defects in the construction and curing stages, and the defects in the construction stage cause the following defects in the curing stage. As in Figure 3b, the defects in each stage should be dealt with measures based on the feedback in the stage where the causes of the defects were identified. As such, this study separated the causes of defects by work type into the DCC stages and proposed a management method through an integrated analysis.

**Figure 3. Integrated defect analysis of design, construction, and curing (DCC): (a) DCC integrated review; (b) DCC integrated measure.**

Existing studies on defect management in apartment buildings [14–19] only present basic data on defect management by analyzing the types or causes of defects by individual types of work using defect occurrence data, but did not present fundamental preventive measures. However, this study recognizes the causes of defects in buildings as continuous actions in the design, construction, and curing phases, as shown in Figure 3. Therefore, measures are taken at the stage where DCC integrated management causes building defects. As such, the DCC integrated management concept in this study is differentiated in
that it can solve the fundamental cause of defects, unlike conventional defect management methods.

4. Defect Data Analysis of Finish Works

4.1. Defect Data Survey

The survey objects for the defects in apartment finishing works are apartment building projects in Korea, which were commenced and completed by five different construction companies in the same area. For construction projects affected by time and climate, it was determined to be important to maintain the consistency in the analysis of defect types and causes; therefore, the study selected as the target projects those performed in the same period. The procedure for data investigation is to request the contractor to confirm the defect when the occupant receives the defect, as shown in Figure 4. The contractor shall visit the household to check defects and register them in the A/S management system.

![Data collection procedure.](image)

As shown in Table 1, there were a total of 3299 households in five projects. These projects commenced in January 2012 and were completed in May 2015. The survey of defect data targeted 69,944 defect cases registered in the after-service management system for one year and five months from June 2016 to November 2016.

| Description | Start      | Completion | No. of Units | No. of Buildings        | Survey Period     |
|-------------|------------|------------|--------------|------------------------|-------------------|
| Project A   |            |            | 511          | B1/F10 to 29, 7 buildings | June 2015–November 2016 |
| Project B   | January 2012 | May 2015  | 636          | B2/F12 to 29, 7 buildings |
| Project C   |            |            | 782          | B2/F15 to 29, 7 buildings |
| Project D   |            |            | 602          | B2/F14 to 29, 7 buildings |
| Project E   |            |            | 768          | B1/F20 to 29, 8 buildings |
| Total       |            |            | 3299         |                        |

As shown in Table 2, the defect types in the surveyed data were divided by work category, such as architectural, mechanical, electrical, communication, and site works. Moreover, the target construction projects were categorized by 11 finishing work trades, as shown in Table 3.

As in Table 2 and Figure 5, when classifying the number of defect cases and ratio in the five apartments by work category, the number of defects in the architectural types was 54,340 (77.7%) out of the 69,944 cases, showing the highest defect type. Furthermore, the number of defects in the mechanical and electrical types was 9984 cases (14.3%) and 3242 cases (4.6%), respectively. In this study, the defects in architectural type that showed the highest defect rate were used for the defect type and cause analysis.
Table 2. Frequency and ratio of the defects by work category.

| Work Category          | Frequency | Ratio (%) | Project          |
|------------------------|-----------|-----------|------------------|
|                        | Total     | Average   | A    | B    | C    | D    | E    |
| Architectural work (WC1) | 54,340    | 10,868    | 77.7 | 7841 | 5826 | 17,148 | 8976 | 14,549 |
| Mechanical work (WC2)   | 9984      | 1997      | 14.3 | 1615 | 636  | 2743  | 2151 | 2839  |
| Electrical work (WC3)   | 3242      | 648       | 4.6  | 597  | 180  | 812   | 595  | 1058  |
| Telecomm. work (WC4)    | 2319      | 464       | 3.3  | 364  | 196  | 589   | 693  | 477   |
| Site work (WC5)         | 59        | 12        | 0.1  | 14   | 2    | 15    | 13   | 15    |

Figure 5. Histogram of the frequency of defects by work category.

As shown in Table 3 and Figure 6, the study analyzed the defect frequency using 11 architectural work trades. Among the 54,340 defects in the architectural work trade, the open work defects corresponding to defects on doors and windows were 12,644 (23.3%), occupying the largest portion of the defects, followed by the furnishing work (9372 cases; 17.2%), tiling work (6091 cases; 11.2%), and painting (5370 cases; 9.9%). In Table 3, several other work trades in which the defect frequency was low were indicated as “others.”

Table 3. Frequency and ratio of defects by work trade of each project.

| Rank | Work Trade | Frequency | Ratio (%) | Project          |
|------|------------|-----------|-----------|------------------|
|      |            | A    | B    | C    | D    | E    |
| 1    | Opening    | 12,644 | 1534 | 1359 | 4238 | 2022 | 3491 |
| 2    | Furnishing | 9372  | 1205 | 779  | 2476 | 2142 | 2770 |
| 3    | Tiling     | 6091  | 733  | 482  | 2233 | 1048 | 1595 |
| 4    | Painting   | 5370  | 994  | 768  | 2270 | 498  | 840  |
| 5    | Flooring   | 5066  | 723  | 397  | 1338 | 958  | 1650 |
| 6    | Joinery    | 4494  | 872  | 697  | 1043 | 693  | 1189 |
| 7    | Paping     | 4476  | 739  | 467  | 1450 | 529  | 1291 |
| 8    | Metal      | 3355  | 505  | 460  | 907  | 537  | 946  |
| 9    | Stone      | 1275  | 169  | 176  | 334  | 151  | 445  |
| 10   | Glazing    | 546   | 41   | 43   | 254  | 90   | 118  |
| 11   | Others     | 1651  | 326  | 198  | 605  | 308  | 214  |

Total 54,340 100 7841 5826 17,148 8976 14,549

Note. (1) Plastic windows and wood doors.
4.2. Defect Type Analysis

Table 4 shows the defect types of 10 work trades among the 11 work trades in Table 3, excluding “Others”, analyzed according to the Pareto principle [52]. The defect type analysis was conducted by selecting five work trades, taking 80% of the defect frequency.

Table 4. Analysis of the defect types by work trade.

| Work Trade (WT) | Defect Type (DT) |
|-----------------|------------------|
| 1. Opening      | poor opening and closing (DT1), condensation (DT2), scratches (DT3), broken frame (DT4), and poor working (DT5), etc. |
| 2. Furnishing   | poor installation (DT1), scratches (DT2), poor opening and closing (DT3), poor wrapping (DT4), and poor shape (DT5), etc. |
| 3. Tiling       | bad joint (DT1), broken (DT2), slope error (DT3), scratches (DT4), and poor gluing (DT5), etc. |
| 4. Painting     | mispainting (DT1), poor surface (DT2), peeling off (DT3), scratches (DT4), and contamination (DT5) |
| 5. Flooring     | uplifting (DT1), scratches (DT2), poor calking (DT3), damaged (DT4), and gap (DT5), etc. |
| 6. Joinery      | condensation & mold (DT1), scratches (DT2), poor fixing (DT3), damaged (DT4), and uplifting (DT5) etc. |
| 7. Papering     | uplifting (DT1), damaged (DT2), poor finishing (DT3), mispasting (DT4), and poor surface (DT5), etc. |
| 8. Metal        | poor opening and closing (DT1), poor finishing (DT2), scratches (DT3), poor fixing (DT4), and gap (DT5), etc. |
| 9. Stone        | Scratches (DT1), damaged (DT2), poor finishing (DT3), bad joint (DT4), and contamination (DT5), etc. |
| 10. Glazing     | poor calking (DT1), damaged (DT2), scratches (DT3), contamination (DT4), and poor finishing (DT5), etc. |

As in Table 4, to manage the defect types systematically, the 10 work trades are indicated using acronyms from WT1 to WT10, and the defect types by work trade are categorized by the order of frequency of key defects from DT1 to DT5. For example, opening work is divided into poor opening and closing (DT1), condensation (DT2), scratches (DT3), broken frame (DT4), and poor working (DT5), etc. As for finishing work, shown in Table 4, the defects that can be visually confirmed, such as scratches, damaged, poor finishing, contamination, or uplifting, are common. Furthermore, in case of opening, furnishing, and metal work, poor opening and closing were the common defect, and as for flooring, papering work, uplifting was the most frequent defect. The study verified that such a tendency was due to the characteristics of the work trades.

Table 5 shows the analysis results of the frequencies of the top five defect types and their ratios by work trade. For example, DT1, DT2, DT3, DT4, and DT5, etc., in the opening work (WT1) were 4507 cases (35.7%), 1787 cases (14.1%), 1466 cases (11.6%), 1350 cases (10.7%), 1200 cases (9.5%), and 2334 cases (18.4%), respectively.

As for the defect characteristics by work trade in Table 5, opening work (WT1) showed poor opening and closing (DT1) as the most common defect (35.7%), and poor installation (DT1) in furnishing work (WT2) showed the highest defect frequency and ratio. Moreover, the most defects found in the other work trades were shown to occur owing to the lack of skill or workmanship by workers. In other words, most defects were shown to be produced in the construction stage. However, in the case of defect joinery work (WT6), condensation and mold caused by the use of low-quality insulation material or the design mistakes in insulation material had the largest defect frequency and ratio; i.e., the defects caused by the errors in the design stage were the largest factor. The results analyzed in Table 5 are used in the DCC integrated analysis of the causes of defects and solutions.
Table 5. Frequencies and ratios by defect type of each work trade.

| Work Trade       | Defect Type | Frequency | Ratio (%) | Work Trade       | Defect Type | Frequency | Ratio (%) |
|------------------|-------------|-----------|-----------|------------------|-------------|-----------|-----------|
|                  | DT1         | 4507      | 35.7      | DT1              | 1506        | 33.5      |
| Opening work     | DT2         | 1787      | 14.1      | DT2              | 706         | 15.7      |
| (WT1)            | DT3         | 1466      | 11.6      | Joinery work     | DT3         | 525       | 11.7      |
|                  | DT4         | 1350      | 10.7      | (WT6)            | DT4         | 430       | 9.6       |
|                  | DT5         | 1200      | 9.5       | DT5              | 430         | 9.6       |
| Others           | 2334        | 18.4      |           | Others           | 897         | 19.9      |
| Furnishing work  | DT1         | 2166      | 23.1      | DT1              | 1366        | 30.5      |
| (WT2)            | DT2         | 1717      | 18.3      | DT2              | 651         | 14.5      |
|                  | DT3         | 1414      | 15.1      | DT3              | 588         | 13.2      |
|                  | DT4         | 1212      | 12.9      | DT4              | 498         | 11.1      |
|                  | DT5         | 1068      | 11.4      | DT5              | 495         | 11.1      |
| Others           | 1795        | 19.2      |           | Others           | 878         | 19.6      |
| Tiling work      | DT1         | 2115      | 34.7      | DT1              | 1291        | 38.5      |
| (WT3)            | DT2         | 1514      | 24.9      | DT2              | 406         | 12.1      |
|                  | DT3         | 961       | 15.8      | DT3              | 387         | 11.5      |
|                  | DT4         | 562       | 9.2       | DT4              | 322         | 9.6       |
|                  | DT5         | 337       | 5.5       | DT5              | 297         | 8.9       |
| Others           | 602         | 9.9       |           | Others           | 652         | 19.4      |
| Painting work    | DT1         | 3174      | 59.1      | DT1              | 475         | 37.3      |
| (WT4)            | DT2         | 768       | 14.3      | DT2              | 372         | 29.2      |
|                  | DT3         | 586       | 10.9      | DT3              | 97          | 7.6       |
|                  | DT4         | 463       | 8.6       | DT4              | 79          | 6.2       |
|                  | DT5         | 164       | 3.1       | DT5              | 75          | 5.9       |
| Others           | 215         | 4.0       |           | Others           | 177         | 13.8      |
| Flooring work    | DT1         | 1680      | 33.2      | DT1              | 305         | 55.9      |
| (WT5)            | DT2         | 1454      | 28.7      | DT2              | 73          | 13.4      |
|                  | DT3         | 749       | 14.8      | DT3              | 64          | 11.7      |
|                  | DT4         | 435       | 8.6       | DT4              | 40          | 7.3       |
|                  | DT5         | 184       | 3.6       | DT5              | 15          | 2.7       |
| Others           | 564         | 11.2      |           | Others           | 49          | 9.0       |

5. DCC Integrated Analysis of Defects

5.1. Survey of Defect Causes

The analysis of the causes of defects in construction projects was performed on 10 work trades from DT1 to DT5 by the defect type, as shown in Table 5. In collaboration with 10 specialists in architectural finishing work with over ten years of experience, we conducted a brainstorming meeting, which led to the identification of the causes of defects by dividing them into those in the DCC stages. Then, we conducted a survey related to architectural finishing work using a five-point Likert scale, as shown in Table 6, with five site engineers and supervisors who had over ten years of experience based on the identified cause.
Table 6. The five points of the Likert scale.

| Description | Very Disagree | Disagree | Normal | Agree | Very Agree |
|-------------|---------------|----------|--------|-------|------------|
| Scale       | 1             | 2        | 3      | 4     | 5          |

The survey results were summarized using the score for each item, wherein the higher the score, the more likely it was that the defect would occur. For example, in Table 7, the causes of poor opening and closing in opening work (WT1) were 29 in total: 10 in the design stage, 15 in the construction stage, and 4 in the curing stage.

Table 7. Causes of defects by defect type and DCC stage of finishing work trades.

| Defect Type          | Design | Const. | Curing | Total | Work Trade          | Defect Type          | Design | Const. | Curing | Total |
|----------------------|--------|--------|--------|-------|---------------------|----------------------|--------|--------|--------|-------|
| Opening work (WT1)   |        |        |        |       | Joinery work (WT6)  |                      |        |        |        |       |
| DT1                  | 10     | 15     | 4      | 29    |                     | DT1                  | 5      | 11     | 3      | 19    |
| DT2                  | 8      | 9      | 2      | 19    |                     | DT2                  | 5      | 7      | 5      | 17    |
| DT3                  | 7      | 7      | 5      | 19    |                     | DT3                  | 5      | 8      | 3      | 16    |
| DT4                  | 7      | 8      | 2      | 17    |                     | DT4                  | 5      | 7      | 5      | 17    |
| DT5                  | 6      | 10     | 1      | 17    |                     | DT5                  | 5      | 8      | 3      | 16    |
| Sum                  | 38     | 49     | 14     | 101   |                     | Sum                  | 25     | 41     | 19     | 85    |
| Furnishing work (WT2)|        |        |        |       | Papering work (WT7) |                      |        |        |        |       |
| DT1                  | 7      | 10     | 2      | 19    |                     | DT1                  | 4      | 9      | 3      | 16    |
| DT2                  | 9      | 10     | 2      | 21    |                     | DT2                  | 4      | 6      | 3      | 13    |
| DT3                  | 8      | 10     | 0      | 18    |                     | DT3                  | 4      | 5      | 3      | 12    |
| DT4                  | 9      | 11     | 2      | 22    |                     | DT4                  | 3      | 6      | 2      | 11    |
| DT5                  | 7      | 12     | 3      | 22    |                     | DT5                  | 3      | 5      | 2      | 10    |
| Sum                  | 40     | 53     | 9      | 102   |                     | Sum                  | 18     | 31     | 13     | 62    |
| Tiling work (WT3)    |        |        |        |       | Metal work (WT8)    |                      |        |        |        |       |
| DT1                  | 5      | 7      | 2      | 14    |                     | DT1                  | 5      | 9      | 3      | 17    |
| DT2                  | 5      | 5      | 2      | 12    |                     | DT2                  | 4      | 6      | 2      | 12    |
| DT3                  | 4      | 4      | 0      | 8     |                     | DT3                  | 3      | 4      | 2      | 9     |
| DT4                  | 5      | 7      | 2      | 14    |                     | DT4                  | 4      | 6      | 2      | 12    |
| DT5                  | 5      | 3      | 0      | 8     |                     | DT5                  | 5      | 5      | 1      | 11    |
| Sum                  | 24     | 26     | 6      | 56    |                     | Sum                  | 21     | 30     | 10     | 61    |
| Painting work (WT4)  |        |        |        |       | Stone work (WT9)    |                      |        |        |        |       |
| DT1                  | 3      | 5      | 0      | 8     |                     | DT1                  | 6      | 11     | 3      | 20    |
| DT2                  | 3      | 9      | 2      | 14    |                     | DT2                  | 6      | 11     | 3      | 20    |
| DT3                  | 3      | 6      | 2      | 11    |                     | DT3                  | 4      | 4      | 2      | 10    |
| DT4                  | 0      | 4      | 2      | 6     |                     | DT4                  | 4      | 4      | 3      | 11    |
| DT5                  | 3      | 5      | 2      | 10    |                     | DT5                  | 4      | 5      | 2      | 11    |
| Sum                  | 12     | 29     | 8      | 49    |                     | Sum                  | 24     | 35     | 13     | 72    |
| Flooring work (WT5)  |        |        |        |       | Glazing work (WT10) |                      |        |        |        |       |
| DT1                  | 4      | 7      | 3      | 14    |                     | DT1                  | 4      | 6      | 3      | 13    |
| DT2                  | 4      | 5      | 3      | 12    |                     | DT2                  | 5      | 8      | 3      | 16    |
| DT3                  | 4      | 5      | 1      | 10    |                     | DT3                  | 5      | 8      | 3      | 16    |
| DT4                  | 4      | 5      | 3      | 12    |                     | DT4                  | 3      | 4      | 2      | 9     |
| DT5                  | 3      | 5      | 0      | 8     |                     | DT5                  | 3      | 6      | 3      | 12    |
| Sum                  | 19     | 27     | 10     | 56    |                     | Sum                  | 20     | 32     | 14     | 66    |

As such, the analysis results of the causes by the defect type in the 10 work trades are shown in Table 7, where WT1 had 101, WT2 had 102, and WT10 had 66 causes. It was characteristic that the defect frequency was high in the opening and furnishing works, as shown in Table 3, but they also had many defect causes, as shown in Table 7. Furthermore, the defect frequency in the joinery work was the sixth highest, but the number of causes of defects was 85, which was the third highest among the defects. The reason for this was this work trade was complex, and quality control was difficult. Therefore, this work trade needs a DCC integrated management more than the others.
Table 8 shows the causes of defects by defect type in the DCC stage analyzed in Table 7. The causes of defects of 10 key work trades, extracted by the participation of experts, were 710 cases in total that included 241 cases in the design stage (34.0%), 353 cases in the construction stage (49.7%), and 116 cases in the curing stage (16.3%). The causes of defects in the design and construction stages are very high at 87.3%.

Therefore, to reduce the defect frequency in finishing works, a more focused management in the construction and design stages is necessary. In particular, as has been verified in Tables 5 and 7, defects caused by workers’ insufficient skill or workmanship in the construction stage take the largest number in the frequency and ratio of the defects, and it is necessary to establish a corresponding quality management strategy.

Table 8. Sum of the defect causes by DCC stage.

| Project Stage   | Defect Causes | Subtotal | Average | Ratio (%) |
|-----------------|---------------|----------|---------|-----------|
| Design stage    |               | 241      | 4.8     | 34.0      |
| Construction stage |           | 353      | 7.1     | 49.7      |
| Curing stage    |               | 116      | 2.3     | 16.3      |
| Total           |               | 710      | 4.7     | 100.0     |

5.2. DCC Integrated Analysis of Defect Causes

When addressing the causes of the defects analyzed in Tables 7 and 8, a lot of finishing work defects in apartment buildings may be resolved. However, it is difficult to present solutions that cope with all causes given the limited research period. Therefore, we selected the top three causes from the defect causes analyzed in Table 7 by defect type and DCC stage; i.e., the defect causes were evaluated and summarized by five site engineers and supervisors who had over ten years of experience and who had participated in the survey, assessing the three defect causes with the highest Likert scale score. Furthermore, a DCC integrated analysis was performed on these defect causes.

Table 9 shows the summary of the top three defect causes among those in the joinery work; it is the result of the DCC integrated analysis on the defect causes in five defect types in the joinery work, as shown in Tables 4 and 7. For example, the DCC integrated analysis of the top three defect causes in condensation and mold (DT1) first showed the causes related to insulation. As shown in Figure 7a, there was an error in the arrangement of seamless insulation in the design stage. Moreover, in the construction stage, the design error was not identified, and in the curing stage, the insulation performance was not checked. If such an error had been identified and measures had been taken in one of the DCC stages, no condensation and mold would have occurred.

The second defect cause was insulation design of low quality, and also in this case, if the error was not detected in the construction and curing stages, condensation and mold occurred. The third defect cause was inappropriate design and construction in the thickness and location of insulation. Furthermore, in the curing stage, the indoor temperature was not appropriately managed. Scratches (DT2) and damages (DT4) commonly showed the defect causes related to the corner beads of walls, structural stability of dry walls, and quality of wall finishes, and Table 9 also showed the related results from the DCC integrated analysis. Poor fixing (DT3) and uplifting (DT5) also have similar defect causes linked to grooves at the wall joints, dry walls, and ceiling boards. The causes by defect type in Table 9 are connected to the DCC stages. Thus, conducting a DCC integrated analysis is a way to systematically check defect causes.
Table 9. DCC integrated analysis of the defect causes of joinery work (WT6).

| DT   | Design Stage                                      | Construction Stage                                      | Curing Stage                                      | Rank |
|------|--------------------------------------------------|--------------------------------------------------------|---------------------------------------------------|------|
| DT1  | -Non-seamless insulation design                  | -No seamless insulation installation                   | -Insulation performance not measured              | 1    |
|      | -Low-quality insulation design                   | -Low-quality insulation installation                   | -Insufficient moisture control                    | 2    |
|      | -Insufficient thickness at the top floor insulation | -Poor insulation around steel door                     | -Inadequate temperature control                   | 3    |
| DT2  | -Undesigned corner bead                         | -Uninstalled corner bead                               | -Wall corner not protected                        | 1    |
| DT4  | -Lack of the structural stability of dry wall    | -Poor installation of dry wall frame                   | -Damaged from other works                         | 2    |
|      | -Poor quality of wall finishes                  | -No quality test of wall finishes                     | -Insufficient quality check                        | 3    |
| DT3  | -Undesigned groove at wall joints               | -Joint work without groove                            | -Joint lift not checked                            | 1    |
| DT5  | -Dry wall fixing interval not considered         | -Ceiling plasterboard poorly fixed                     | -Damaged from other works                         | 2    |
|      | -Plasterboard fixing height not considered       | -Inconsistency with the ceiling board line             | -Insufficient quality control                      | 3    |

Figure 7. Design improvement for DT1: (a) existing design with non-seamless insulation; (b) improved design with seamless insulation for the case project.

5.3. DCC Integrated Solutions for Defects

We have so far analyzed the defect causes of finishing work trades using the defect types and DCC stage in Tables 7 and 8, and as in the cases of Table 9, the study conducted a DCC integrated analysis on the defect causes. Next, the study extracted the solutions for the defects by defect types with the help of the experts who participated in the survey and summarized the results using the DCC stage, as shown in Table 10.
As the defect causes were mostly shown in the construction stage (49.7%), most solutions were also proposed in the construction stage (50.6%), as shown in Table 10. The reason why there were more solutions than the defect causes was because indirect preventive solutions, such as factory inspection, material inspection and testing, and site measurement, were additionally proposed in addition to the direct solutions.

Table 10. Proposed solutions for defects using the DCC stage.

| Project Stage | Solutions | Ratio (%) |
|---------------|-----------|-----------|
| Design stage  | 298       | 34.6      |
| Construction stage | 435       | 50.6      |
| Curing stage  | 127       | 14.8      |
| **Total**     | **860**   | **100.0** |

Table 11 shows the causes of joinery work (WT6) among the solutions summarized in Table 10. In this table, a total of 21 solutions, including seven in the design, 11 in the construction, and 3 in the curing stage, were proposed to avoid condensation and mold (DT1). Similarly, 18, 17, 18, and 17 solutions were proposed for DT2, DT3, DT4, and DT5, respectively. Despite some differences with respect to defect types, the solutions for WT6 in the construction stage were almost half of the total solutions (49.4%), similar to that of the causes in Table 8. However, compared with the defect causes in the design stage at 34%, the solutions were reduced to about 29.7%, and more solutions were presented in the curing stage.

Table 11. Proposed solutions by defect type of WT6.

| Defect Type | Design Stage | Construction Stage | Curing Stage | Subtotal |
|-------------|--------------|--------------------|--------------|---------|
| DT1         | 7            | 11                 | 3            | 21      |
| DT2         | 5            | 8                  | 5            | 18      |
| DT3         | 5            | 9                  | 3            | 17      |
| DT4         | 5            | 8                  | 5            | 18      |
| DT5         | 5            | 9                  | 3            | 17      |
| **Total**   | **27**       | **45**             | **19**       | **91**  |
| **Ratio (%)** | **29.7**     | **49.4**           | **20.9**     | **100.0** |

Table 12 shows the summary of the top three defect causes among those in the joinery work. It is the result of the DCC integrated analysis on the defect causes in five defect types in the joinery work, as shown in Table 11. For example, the DCC integrated analysis of the top three defect causes in condensation and mold (DT1) showed, firstly, the causes related to insulation. As shown in Figure 7b, the insulation is arranged without seams in the design stage and is installed according to the design in the construction stage, and the insulation performance is measured in the curing stage to verify the quality; that is, by conducting the DCC integrated management, no condensation and mold would occur.
In the second measure, the high-quality insulation is reflected on the design, and the right insulation defined in the drawing and specification is installed in the construction stage. In the curing stage, regular ventilation management is performed in said internal space. In the third measure, an appropriate design and construction is performed on the thickness and location of the insulation, and in the curing stage, an appropriate indoor temperature is maintained.

In a similar method, DCC integrated solutions related to quality DCC were proposed for the corner bead of wall, structural stability of dry wall, and quality of wall finishes in scratches (DT2) and damages (DT4). For example, to cope with the defects related to the lack of structural stability of a dry wall in Table 9, the lintel must be arranged on top of the dry wall opening in the design stage, and the quality of installation of the lintel and right stud height over the dry wall must be guaranteed in the construction stage.

In the curing stage, the installed lintel and stud should be well protected from damage by other work. The solutions for poor fixing (DT3) and uplifting (DT5) were also presented by the DCC integrated management in Table 13. If the DCC integrated solutions by defect type, shown in Table 13, are applied, it is highly likely that the concerned defects may not occur. The study presented the DCC integrated solutions for the defects analyzed in Table 7, and shown in Table 13 are examples of joinery work (WT6).

**Table 12.** DCC integrated solutions to the defect causes of joinery work (WT6).

| DT  | Design Stage                                                                 | Construction Stage                                                                 | Curing Stage                                                                 |
|-----|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| DT1 | Seamless insulation design                                                   | Seamless insulation installation                                                  | Measurement with thermal imaging camera                                     |
| DT1 | -Anticondensation insulation design                                          | -Anticondensation insulation installation                                        | -Periodic ventilation                                                       |
| DT1 | -Sufficient thickness for the top floor insulation                           | -Groove design around steel door                                                 | -Securing indoor temperature through room heating                           |
| DT2 | Corner bead design                                                           | Corner bead installation                                                          | -Wall corner protection                                                      |
| DT2 | -Lintel design over dry wall opening                                          | -Securing quality installation of lintel & right stud height over dry wall        | -Protection from other works                                                  |
| DT2 | -Cellulose reinforced cement board design for external wall                  | -Use of products that passed quality test                                         | -Quality check of external wall                                              |
| DT3 | -Groove design at wall joints                                                | -Joint work with groove                                                          | -Checking joint lift                                                         |
| DT3 | -Dry wall runner design at 600 mm interval                                   | -Installing dry wall stud at 10cm lower from the upper runner                     | -Protection from other works                                                  |
| DT3 | -Keeping plasterboard fixation within 10 mm from the rim                     | -Consistent installation with the ceiling board line                              | -Quality check of whole plasterboard fixation                                |
| DT5 | -Jumping groove                                                              | -Joint work using a groove                                                        |                                                                            |
| DT5 | -Joint work using a groove                                                    | -Checking joint lift                                                              |                                                                            |

**Table 13.** DCC integrated solutions to the defect causes of joinery work (WT6).

| DT  | Design Stage                                                                 | Construction Stage                                                                 | Curing Stage                                                                 |
|-----|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| DT1 | Seamless insulation design                                                   | Seamless insulation installation                                                  | Measurement using a thermal imaging camera                                     |
| DT1 | -Anticondensation insulation design                                          | -Anticondensation insulation installation                                        | -Periodic ventilation                                                       |
| DT1 | -Sufficient thickness for the top floor insulation                           | -Groove design around a steel door                                                 | -Securing indoor temperature through room heating                           |
| DT2 | Corner bead design                                                           | Corner bead installation                                                          | -Wall corner protection                                                      |
| DT2 | -Lintel design over dry wall opening                                          | -Insufficient dry wall stud height from the upper runner                           | -Protection from other works                                                  |
| DT2 | -Cellulose reinforced cement board design for external wall                  | -Use of products that passed the quality test                                    | -Quality check of external wall                                              |
| DT3 | -Groove design at wall joints                                                | -Joint work using a groove                                                        | -Checking joint lift                                                         |
6. Verification of DCC Integrated Management

6.1. Case Application

6.1.1. Description of the Case Project

We have described the DCC integrated management that can extract the cause analysis on the defects in finishing work and solutions. To verify the effectiveness of the proposed DCC integrated management, the study selected the joinery work based on the results from the preliminary research as a case study. As shown in Table 14, the case project was a residential building project consisting of 19 buildings that had 25 storeys and one underground level that accommodated 1604 households, located in Incheon, South Korea. The project commenced in December 2016 and was completed in January 2019, and the DCC integrated solutions were applied to the defects of joinery work, introduced in Table 11, as a case study.

Table 14. Description of a case apartment project.

| Description          | Contents                     | Remarks                                      |
|----------------------|------------------------------|----------------------------------------------|
| Location             | Incheon, Korea Rep.          |                                              |
| Construction period  | December 2016–January 2019  |                                              |
| Site area            | 90,174 m²                    | Analysis of results from February            |
| Building area        | 12,757 m²                    | 2019 to July 2020 after applying DCC solutions |
| Volume               | 178%                         |                                              |
| No. of housing units | 1604                         |                                              |
| No. of buildings     | B1–F25, 19 buildings         |                                              |
| Structure            | Bearing wall system          |                                              |

6.1.2. Application of DCC Integrated Solutions

Because of the word limit, it is difficult to describe the whole content of the 91 solutions introduced in Table 11. Therefore, in this study, insulation work, one of the solutions for condensation and mold (DT1) that has the highest defect frequency among the defects, was described. For reference, previous research confirmed that condensation and mold in joinery work has the highest defect risk, and thus, it is essential to apply the DCC integrated solutions to the defect [53,54].

As described in Table 13, DCC integrated solutions, such as seamless insulation design, installation, and the measurement of insulation performance using a thermal imaging camera at the curing stage, were applied to solve DT1. Previously, heat bridge phenomena occurred, resulting in condensation and mold at the point where the internal and external walls met, as shown in Figure 7a; but, as shown in Figure 7b, such an issue was resolved by the seamless insulation design and installation. Figure 8a shows the existing project where black insulation was installed on the inside of the external reinforced concrete (RC) wall, but it was cut by the internal wall installed perpendicular to the external wall. Figure 8b shows that the pink seamless insulation was installed inside the external RC wall, and the interior wall was installed as the screen wall. Previously, the insulation material was separated owing to the interference of the internal wall, but in the improved case, as shown in Figure 8b, the internal RC WALL was removed to allow seamless installation.
Figure 8. Seamless insulation design and installation: (a) separated insulation design and installation; (b) seamless insulation design and installation.

As in the previous case, where the insulation installed in the external wall was cut by the internal wall, as shown in Figure 9a, the measurement using a thermal imaging camera verified the bad condition of the internal wall contaminated with condensation and mold. Moreover, as in Figure 9b, in the case where the seamless insulation was installed in the external wall, separating from the internal wall, the measurement showed a good condition of the internal wall without condensation and mold. The thermography techniques for detecting defects in building envelopes, such as missing insulation, thermal bridging, and cracks and moisture problems, using a thermal imaging camera, have been discussed in various studies [55–57]; thus, no detailed explanation is given in this study. Further examples of improvements can be found in the Appendix.

Figure 9. Measurement of a building envelope using a thermal imaging camera: (a) bad condition of internal wall contaminated with condensation and mold; (b) good condition of the internal wall.

6.2. Defect Analysis by Defect Type

After applying the DCC integrated solutions, the study analyzed the defects registered on the after-service management system between February 2019 and July 2020. There were in all 1798 defects in the joinery work. As shown in Table 15, the results of the defect analysis by defect type were 209 cases in condensation and mold (11.6%), 185 cases in scratches (10.3%), 98 cases in poor fixing (5.5%), 145 cases in damages (8.1%), and 140 cases in uplifting (7.8%). It was determined that the defects, despite the application of the DCC integrated management, were due to the heating and poor ventilation and other reasons due to careless use by residents and the damage of the facilities by young resident children.
Table 15. Defect analysis by the defect type of case work.

| Defect Type                         | Frequency | Ratio  |
|-------------------------------------|-----------|--------|
| Condensation and mold (DT1)         | 209       | 11.6%  |
| Scratches (DT2)                     | 185       | 10.3%  |
| Poor fixing (DT3)                   | 98        | 5.5%   |
| Damaged (DT4)                       | 145       | 8.1%   |
| Uplifting (DT5)                     | 140       | 7.8%   |

6.3. Verification of the Effectiveness of Defect Prevention

As in Table 16, the defect measures on the key defect causes in joinery work were applied to new projects, and as a result, the number of defects in the apartment for verification decreased by 2043 cases (56.80%) compared with the three survey apartments. While the defect period was identical, the surveyed apartment projects had a total of 3299 households, whereas the apartments for verification had 1604 households. Considering the twofold difference in the number of households, the defect frequency was compensated.

As a result, condensation and mold was reduced by 1088 cases (72.24%), scratches were reduced by 336 cases (47.59%), poor fixing was reduced by 329 cases (62.67%), damage was reduced by 140 cases (32.56%), and uplifting was reduced by 150 cases (34.88%). The result of the application of the DCC integrated management showed that the defect prevention was the most effective on condensation and mold (DT1), followed by poor fixing (DT3) and scratches (DT2).

Table 16. Verification of the effectiveness of defect prevention in joinery work.

| Defect Type | Defect Frequency in the Surveyed Apartments (3299 Households) | Defect Frequency of the Apartments for Verification (1604 Households) | Compensation of Defect Frequency (Considering the Twofold Household Difference) | Reduced Frequency of Defects | Reduction Effect (%) |
|-------------|---------------------------------------------------------------|-------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------|---------------------|
| DT1         | 1506                                                          | 209                                                               | 418                                                                             | 1088                         | 72.24               |
| DT2         | 706                                                           | 185                                                               | 370                                                                             | 336                          | 47.59               |
| DT3         | 525                                                           | 98                                                                | 196                                                                             | 329                          | 62.67               |
| DT4         | 430                                                           | 145                                                               | 290                                                                             | 140                          | 32.56               |
| DT5         | 430                                                           | 140                                                               | 280                                                                             | 150                          | 34.88               |
| Total       | 3597                                                          | 777                                                               | 1554                                                                            | 2043                         | 56.80               |

7. Discussion

In this study, the DCC integrated management was applied to the joinery work of the case project, as discussed in Chapter 5, and its effectiveness was verified. If the analysis process for defect types and causes verified through the case study is to be systemized, a swifter and more efficient defect management would be possible for apartment buildings. The DCC integrated DMS (Defects Management System) to be developed in the future will be operated as shown in Figure 10.
Figure 10. DMS operation process.

As shown in Figure 10, the DMS will first select the type of construction (Step 1) and then the type of defect (Step 2). In the current stage, five types of defects are offered by each type of construction, but through further studies in the future, additional defect types will be added. Later, the defect causes will be reviewed (Step 3). The causes are divided into those in the design, construction, or curing stages, from the viewpoint of the user (designer and owner), and their causes will be verified (Step 4). If the defect causes cannot be accurately verified, the defect causes are reviewed again (feedback to Step 3). Once the defect causes per stage are accurately verified, the defect measure in the integrated management in the DCC stages will be established (Step 5). After the review of the established defect measures (Step 6), finally, they will be applied to the case, and their effectiveness will be verified (Step 7). In addition to the verification of the defect types and causes of the finish work, this study produced additional results of developing a DCC integrated DMS to establish defect measures by type more effectively. The proposed DMS concept can be used in determining a defect prevention measure more effectively and swiftly in the future.

In addition, defects in buildings in terms of life cycle assistance (LCA) are divided into stages of design, construction, curing, maintenance and demolition. Defects in the building are the result of poor design, construction, and curing, resulting in defects after completion. In other words, defects in the building depend on whether quality is secured or not during the DCC phase. As such, DCC integrated management for defect prevention is very important in terms of LCA. In the maintenance phase, defects are caused by indirect causes, such as residents’ careless behavior. In terms of future LCA, DCC integrated management research is also needed to prevent defects.

As previously explained, most of the preceding studies only list the types of defects or causes of each type of work using defects data. However, in this study, a plan has been proposed to manage defects by integrating the design, construction, and curing phases. These DCC integrated management measures have been validated through case application. However, there is a limitation in that this study was conducted on apartment buildings due to the difficulty of obtaining data. In the future, it is necessary to analyze defects in various buildings, such as general buildings, by securing continuous data.
8. Conclusions

This study analyzed the defect causes and solutions in the finishing work in apartment building projects by targeting already completed apartment buildings in South Korea through the DCC stages and proposed a DCC integrated management. Moreover, the proposed DCC integrated management was applied to a case project to verify its effectiveness. Among them, as shown in Table 2, the defects in the architectural work were the highest at 54,340 cases (77.7%), and defects in the site work were the least, with 59 cases (0.1%). Among the defects in the architectural work, the defects in the opening work were the highest at 12,644 cases (23.3%) and those in the glazing work were the least, at 546 cases (1.0%), as shown in Table 3. The results of this study are as follows.

First, the frequency of defects in each of the 11 architectural work trades at the case sites was analyzed. As a result, among a total of 54,340 architectural works, the opening work accounted for the largest portion with 12,644 (23.3%). In addition, 9372 cases (17.2%) of furnishing work were reported. Tiling work accounted for 6091 cases (11.2%) and painting work accounted for 5370 cases (9.9%).

Second, the defect types for each type of work were investigated and the cause of the defect was analyzed. For example, in the case of opening work (WT1), opening and closing (DT1) accounted for the highest proportion at 35.7%. In the case of furnishing work (WT2), floor installation (DT1) has the most defects.

Third, the DCC integrated management method of defects is proposed. The cause of defects can be systematically identified, and sustainable quality control is possible. The application of the proposed DCC integrated management to the joinery work in a case project showed that, compared with the apartment building projects surveyed in the previous study, the defect frequency in the case project was reduced by a total of 2043 cases (56.80%). This demonstrates that the DCC integrated management is a very effective tool in preventing defects.

As such, this study analyzed the causes of defects in apartment buildings by dividing them into design, construction, and curing stages. Later, the DCC integrated management concept was proposed, which allows integrated management of the causes of defects in stages. DCC integrated management recognizes the cause of defects in a building as a continuous action in the design, construction and curing stages, so feedback measures can be taken in the stage of defects. As a result of its application to the joinery construction of the case project, the DCC integrated defect management technique was verified. The results of this study will be used as a basis for defect prevention measures for high-quality finishing work, and the management concept presented in this study can be used as a reference for building a defect management system.

This study offered five key defect types by construction type, but it is necessary to conduct additional research on other additional defect types in the future. The results of this study will be used as the basic data for the establishment of defect prevention measures for high-quality finishing work in construction projects and will offer a core concept in the establishment of a DCC integrated DMS.

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Appendix

A1. Improving the Quality of Insulation

As shown in Figure A1a, low-quality insulation was originally installed at the construction stage. As a result, condensation defects and damage by mold occurred. To improve this case, anti-condensation insulation materials were adopted to prevent condensation defects and fungal damage, as shown in Figure A1b.

![Figure A1. Improving the quality of insulation: (a) low-quality insulation installation; (b) anti-condensation insulation installation.](image)

A2. Improving of Humidity Condition

As shown in Figure A2a, the windows were kept closed during the curing phase. As a result, poor ventilation and temperature contributed to condensation defects and mold damage. To improve this situation, the windows were opened during the curing stage to keep good ventilation and proper temperature, as shown in Figure A2b.

![Figure A2. Improving of humidity condition: (a) bad control of ventilation and temperature in the existing case; (b) good control of ventilation and temperature.](image)

A3. Groove Wall Design around the Steel Door at Entrance

As shown in Figure A3a, the concrete wall for the entrance steel door was a flat-cut design so that insulation could not be installed on the inside opening wall. As a result, condensation and subsequent mold damage occurred. The condensation problem was solved by installing a groove concrete wall so that insulation can be installed on the inside concrete opening wall insulation, as shown in Figure A3b. The groove wall is shown in the front view of Figure A3b and the insulation is installed around the steel door frame in the detail view.
Figure A3. Improvement around the entrance steel door: (a) no insulation inside concrete wall for the entrance steel door; (b) insulation inside groove wall for the entrance steel door.

A4. Arrangement of Wall Corner Beads

In the initial design, no corner bead was installed in the external corner of the wall, as shown in Figure A4a. As a result, it was confirmed that the external corner of the wall was damaged before the resident’s occupancy. The corner bead was placed in the external corner of the wall to solve this problem, as shown in Figure A4b.

Figure A4. Wall corner bead installation: (a) no corner bead in the external corner of the wall; (b) installing wall corner bead.

A5. Installation of Double-Layer Wall Insulation

As shown in Figure A5a, it was initially designed as single-layer wall insulation, and outside air was inflowed between the insulation panels, causing condensation at that location. It was improved by installing two insulation panels staggeredly, as shown in Figure A5b, to prevent the occurrence of condensation at the joint.
A6. Edge Protection of Papered Wall

As shown in Figure A6a, the edges were not protected after wallpaper work, so the edges were often scratched and damaged by other workers before the resident’s occupancy. However, as shown in Figure A6b, the edges of the papered wall were protected to solve this problem until the resident’s occupancy.

A7. Wall Corner Protection

As shown in Figure A7a, the joints of the insulation panels around the outside window were initially designed to match the width of the window. As a result, condensation and subsequent mold damage occurred. This problem was improved by arranging the joints of the insulation panels around the outside window that do not match the width of the window as shown in Figure A7b.
Figure A7. Improvement of insulation joints around windows: (a) insulation joints matching the width of the window; (b) insulation joints not matching the width of the window.

References

1. Ju, J.H.; Bang, H.S.; Choi, B.J.; Kim, O.K. A Study on the Defect Types and Quality Innovation Methods for Apartment Houses. In Proceedings of the Korean Institute of Building Construction Conference, South Jeju-do, Korea, 16 May 2018; pp. 155–156. (In Korean)
2. Jang, H.M. Assessment of defect risks in apartment projects based on the defect classification framework. JKAIS 2018, 19, 61–68, doi:10.5762/KAIS.2018.19.3.61. (In Korean)
3. Kim, B.S.; Park, J.M.; Choi, J.H.; Seo, D.S.; Kim, O.K. Comparative analysis on repairing cost of lawsuit on concrete crack defect in apartment building. KICEM 2011, 12, 142–150, doi:10.6106/KJCEM.2011.12.6.142. (In Korean)
4. Ministry of Land, Infrastructure and Transport of Korea. 2017. Available online: https://www.law.go.kr/LSW/admRulLs-InfOp.do?admRulSeq=2100000078829 (accessed on 10 March 2021). (In Korean)
5. Lee, S.H. A Study on Quality Improvements of Apartment House by Satisfaction Analysis of Occupants. Master’s Thesis, Hanyang University, Seoul, Korea, 26 August 2004. (In Korean)
6. Lee, D.H.; Shim, U.J.; Suh, H.S.; Ahn, Y.S. A study on the selection of primary management objects in life-cycle phases through analyzing the case of defect in constructing apartment house. JRAAIK 2012, 14, 201–208. (In Korean)
7. Lee, S.H.; Lee, H.S.; Kim, M.H. A method for selecting principal items of quality management through the defect analysis in the construction process. JAIC 1996, 12, 301–309. (In Korean)
8. Suffian, A. Some common maintenance problems and building defects: Our experiences. Procedia Eng. 2013, 54, 101–108, doi:10.1016/j.proeng.2013.03.009.
9. Park, Z.S.; Ahn, Y.S. A study on the impact from cost of quality control in the construction site. JRAAIK 2012, 14, 237–242. (In Korean)
10. Lee, G.H.; Han, D.K.; Lim, H.C. Improvement of defect management of apartment houses through analysis of influencing factors. JRAAIK 2012, 14, 247–254. (In Korean)
11. Seo, D.S.; Um, S.K. A study on types and problems of defect lawsuit on apartment buildings. KIEAE J. 2007, 7, 127–132. (In Korean)
12. Jang, H.S.; Seo, C.H. A study on the improvement of defect information management system of apartment house. JKIBC 2010, 10, 115–123, doi:10.5345/JKIC.2010.10.2.115. (In Korean)
13. Fauzi, S.N.F.M.; Abidin, N.Z. The relationship of housing defects, occupants’ satisfaction and loyalty behavior in build-then-sell houses. Procedia Soc. Behav. Sci. 2012, 62, 75–86, doi:10.1016/j.sbspro.2012.09.014.
14. Mills, A.; Love, P.E.; Williams, P. Defect costs in residential construction. JCE MGMT 2009, 135, 12–16, doi:10.1061/(ASCE)0733-364(2009)135:1(12).
15. Othman, N.L.; Jaafar, M.; Harun, W.M.W.; Ibrahim, F. A case study on moisture problems and building defects. Procedia Soc. Behav. Sci. 2015, 170, 27–36, doi:10.1016/j.sbspro.2015.01.011.
16. Cogurcu, M.T. Construction and Design Defects in the Residential Buildings and Observed Earthquake Damage Types in Turkey. NHESS 2015, 15, 931–945.
17. Bakri, N.N.O.; Mydin, M.A.O. General building defects: Causes, symptoms and remedial work. Eur. J. Technol. Des. 2014, 3, 4–17.
18. Dong, A.; Maher, M.L.; Kim, M.J.; Gu, N.; Wang, X. Construction defect management using a telematic digital workbench. Autom. Constr. 2009, 18, 814–824, doi:10.1016/j.autcon.2009.03.005.
19. Park, J.; Seo, D. Basic Study on Term of Warranty Liability for Finish Work Defect in Apartment Building. Water Supply 2017, 6, 14, doi:10.15242/JRCMCE.EAP171424. (In Korean)
20. Lin, C.L.; Fan, C.L. Evaluation of CART, CHAID, and QUEST algorithms: A case study of construction defects in taiwan. JAABE 2019, 18, 539–553, doi:10.1080/13467581.2019.1696203.
21. 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.

22. Das, S.; Chew, M.Y. Generic method of grading building defects using MFECA to improve maintainability decisions. *J. Perform. Constr. Facil.* **2011**, *25*, 522–533, doi:10.1061/(ASCE)CF.1943-5509.0000206.

23. Yoon, H.I.; Jo, B.S. A study of the law-suit requesting the guarantee against defects in the apartment buildings. *JKIBC* **2007**, *7*, 67–76, doi:10.5345/JKIC.2007.7.2.067. (In Korean)

24. Kim, D.H.; Song, H.; Go, S.S. A study on the defect division system according to work type of apartment house through tenant preliminary research. *AJIK* **2007**, *23*, 127–134. (In Korean)

25. Hong, S.I.; Hyun, C.T.; An, S.B.; Ji, S.M.; Son, M.J. Selection of primary management objects for defect prevention of apartment finishing works. *AJIK* **2011**, *27*, 185–194. (In Korean)

26. Kim, B.O.; Je, Y.D.; Song, H.S.; Lee, S.B. Prediction model development of defect repair cost for apartment house according to performance data. *JKIBC* **2011**, *11*, 459–467, doi:10.5345/JKICB.2011.11.5.459. (In Korean)

27. Ministry of Land, Infrastructure and Transport of Korea. Article 37 of the Code of Practice, Apartment Housing Management Act, 2020. Available online: https://www.law.go.kr/LSiJolLinkP.do?docType=JO&lsNm=%EA%B3%B5%EB%8F%99%EC%A3%BC%ED%83%9D%EA%B4%80%EB%A6%AC%EB%B2%95%EC%8B%9C%ED%96%89%EB%A0%B9&languageType=KO&para=1&joNo=004100000F36(0) (accessed on 10 March 2021). (In Korean)

28. Ministry of Land, Infrastructure and Transport of Korea. Article 36 of the Code of Practice, Apartment Housing Management Act, 2020. Available online: https://www.law.go.kr/LSiJolLinkP.do?docType=JO&lsNm=%EA%B3%B5%EB%8F%99%EC%A3%BC%ED%83%9D%EA%B4%80%EB%A6%AC%EB%B2%95%EC%8B%9C%ED%96%89%EB%A0%B9&languageType=KO&para=1&joNo=004100000F36(0) (accessed on 10 March 2021). (In Korean)

29. Ministry of Land, Infrastructure and Transport of Korea. Reference Table 4, Code of Practice, Apartment Housing Management Act, 2019. Available online: https://www.law.go.kr/LSiJolLinkP.do?docType=JO&lsNm=%EA%B3%B5%EB%8F%99%EC%A3%BC%ED%83%9D%EA%B4%80%EB%A6%AC%EB%B2%95%EC%8B%9C%ED%96%89%EB%A0%B9&languageType=KO&para=1&joNo=004100000FJ7(0) (accessed on 10 March 2021). (In Korean)

30. Josephson, P. Defects and Defect Costs in Construction-A Study of Seven Building Projects in Sweden; Chalmers University of technology: Gothenburg, Sweden, 1998.

31. Khalil, I.W.; Noori, S.A. Diagnosis and Evaluation of Defects Encountered in Newly Constructed Houses in Erbil City, Kurdistan, Iraq. *ETJ* **2019**, *37*, 70–77.

32. Koch, C.; Schultz, C.S. The Production of Defects in Construction-An Agency Dissonance. *Constr. Manag. Econ.* **2019**, *37*, 499–512, doi:10.1080/01446193.2018.1519253.

33. Shirkavand, I.; Lohne, J.; Lædreg, O. Defects at handover in Norwegian construction projects. *Procedia Soc. Behav. Sci.* **2016**, *226*, 3–11, doi:10.1016/j.prosoc.2016.06.155.

34. Plebankiewicz, E.; Zima, K.; Malara, J.; Biel, S. A Procedure of Repairing Housing Defects in Development Investments. In Proceedings of the MATEC Web Conference, Poland, 30 January 2019; pp. 1–7.

35. Tayeh, B.A.; Maqsoom, A.; Aisheh, Y.I.A.; Almanassra, M.; Salahuddin, H.; Qureshi, M.I. Factors affecting defects occurrence in the construction stage of residential buildings in gaza strip. *SN Appl. Sci.* **2020**, 2, 1–12.

36. Ishak, S.N.H.; Chohan, A.H.; Ramly, A. Implications of design deficiency on building maintenance at post-occupational stage. *J. Build. Appl.* **2007**, *3*, 115–124.

37. Chong, W.K.; 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)0887-0826(2006)20:3(213).

38. Ojo, A.; Ifajuyi, O.O. Defective Construction in Residential Buildings: A Study of Sunshine Gardens, Akure Nigeria. *Int. J. Civ. Eng. Constr. Est. Manage.* **2014**, *1*, 16–30.

39. Josephson, P.E. *Causes of Defects in Construction-A Study of Seven Building Projects in Sweden*; Chalmers University of Technology: Göteborg, Sweden; 1998.

40. Al-Hammad, A.; Assaf, S.; Al-Shihah, M. The effect of faulty design on building maintenance. *J. Qual. Maint. Eng.* **1997**, *3*, 29–39, doi:10.1108/13552519710161526.

41. Waziri, B.S. Design and construction defects influencing residential building maintenance in nigeria. *Jordan J. Civ. Eng.* **2016**, *10*, 313–323.

42. Lee, J.E.; Kim, B.Y.; Jeong, B.J. Analysis of Defect repair cost by work type based on defect inspection of apartments. *JKIBC* **2015**, *15*, 491–500, doi:10.5345/JKIBC.2015.15.5.491. (In Korean)

43. Forcada, N.; Macarulla, M.; Gangolettes, M.; Casals, M. Assessment of construction defects in residential buildings in spain. *Build. Res. Inf.* **2014**, *42*, 629–640, doi:10.1080/09613218.2014.922266.

44. Allotey, S.E. An evaluation of the impact of defects in public residential buildings in ghana. *CER* **2014**, *6*, 58–64.

45. Dahanayake, B.; Ramachandra, T.; Thurairajah, N. Assessment on Rework Costs Probability of Housing Projects in Sri Lanka. Proceedings of the 32nd Annual ARCOM Conference, Manchester, UK, 5–7 September 2016; Association of Researchers in Construction Management: London, UK; Volume 2, pp. 1265–1273.

46. Park, C.S.; Lee, D.Y.; Kwon, O.S.; Wang, X. A framework for proactive construction defect management using BIM, Augmented reality and ontology-based data collection template. *Autom. Constr.* **2013**, *33*, 61–71, doi:10.1016/j.autcon.2012.09.010.

47. Yun, S.H.; Park, C.W.; Jeong, S.Y. A study on the integrated construction defects assessment of apartments for systematic asset management. *AJIK* **2008**, *24*, 179–186. (In Korean)
48. Jang, H.M. Assessment of defect risks in apartment projects based on the defect classification framework. *JKAIS* 2019, 20, 510–519, doi:10.5762/KAIS.2019.20.11.510. (In Korean)

49. Lee, M.H.; Yang, S.K. A study on the survey and analysis of the flaw types in the apartment. *JAJK* 1996, 12, 271–281. (In Korean)

50. Kim, S.H.; Kim, J.J. Analysis of defect risk by work types based on warranty liability period in apartments. *KJCEM* 2018, 19, 34–42, doi:10.6106/KJCEM.2018.19.4.034. (In Korean)

51. Kian, P.S. A review of factors affecting building defects in singapore. *CED* 2004, 3, 64.

52. Pareto Analysis. Available online: https://en.wikipedia.org/wiki/Pareto_analysis (accessed on 26 November 2020).

53. Kim, J.H.; Go, S.S. Evaluation of defective risk for the finishing work of apartment house. *KJCEM* 2012, 13, 63–70, doi:10.6106/KJCEM.2012.13.6.063. (In Korean)

54. Oh, S.M.; Park, S.H.; Joung, K.S. Study on the Improvement Plans of Condensation Defect Examples in Apartment Building. *KJACR* 2017, 29, 82–88, doi.org/10.6110/KJACR.2017.29.2.082. (In Korean)

55. Fox, M.; Goodhew, S.; De Wilde, P. Building defect detection: External versus internal thermography. *Build. Environ.* 2016, 105, 317–331, doi:10.1016/j.buildenv.2016.06.011.

56. Li, Z.; Yao, W.; Lee, S.; Lee, C.; Yang, Z. Application of infrared thermography technique in building finish evaluation. *J. Nondestr. Eval.* 2000, 19, 11–19, doi:10.1023/A:1006612023656.

57. Lo, T.Y.; Choi, K.T.W. Building defects diagnosis by infrared thermography. *Struct. Surv.* 2004, 22, 259–263, doi:10.1108/02630800410571571.