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LDA-Based Model for Defect Management in Residential Buildings

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Abstract: This study systematically analyzes various defect patterns that occur during the warranty period of residential buildings using the loss distribution approach (LDA). This paper examines 16,108 defects from 133 residential buildings where defect disputes occurred between 2008 and 2018 in South Korea. The analysis results showed that the defect losses were relatively high in reinforcement concrete (RC) work (3/5/10 years), waterproof work (5 years), and finish work (2 years). It is shown that RC work has a high frequency of defects, such as cracks in concrete in public spaces affected by external factors. In addition, it was analyzed that the type of defect needed high repair cost because the area where the defect—such as incorrect installation and missing task—occurred, needed construction again. According to the level of frequency and severity, losses were divided within four zones to provide detailed strategies (by period). This will effectively contribute to minimizing unnecessary losses from defects as quantifying the losses of defects.

Keywords: defects liability period; risk matrix; residential buildings; loss distribution approach

1. Introduction

The proportion of people living in cities is expected to reach 66% among the global population by 2050. For this trend, apartments are becoming a major residential type in many countries, including Vietnam, Singapore, South Korea, and the United States [1,2].

As the functionality of apartments becomes more complex and higher, the importance of quality management is increasing [3]. The quality control of apartments aims to maintain a high-quality construction environment so that many residents can live in a safe, comfortable, residential environment [4]. In particular, defect management is critical to maintaining the building performance [5]. Thus, defect management can contribute to the sustainability and durability of residential buildings.

However, the construction of apartments causes defects due to the complex interconnections of various work types, unexpected design mistakes, material defects, faults during construction, and environmental factors [6]. Various stakeholders suffer practical damage because significant costs are incurred to solve these defects [7]. Many efforts have been continuously made to ensure the quality and to prevent poor construction of housing [8]. However, conflicts and disputes between residents and contractors can arise due to differences in the interpretations and perceptions of defects that occur after the houses are transferred [9]. Many countries have institutionalized the defect liability period (DLP) to minimize the social losses caused by the defects [10–13]. In the case of the United Kingdom, the DLP is arbitrarily implemented, while in Japan, the DLP is mandatory. As such, DLP in each country operates at various standards.

The DLP obligates the contractor to repair any defects that occur within a set period; however, the obligation is terminated after the set period. Due to this characteristic of the DLP, the contractor should identify various defect risks, including the lack of knowledge of residents, daily wear and tear, and construction failures, while managing the defects efficiently during the warranty period. Furthermore, occupants need to recognize any defects that may occur within the DLP and secure their rights to minimize the defects [12].

Therefore, it is essential for stakeholders to recognize the defect occurrence pattern preemptively to take a rational decision about the defect repair for the DLP [14]. Many studies have attempted to analyze the causes of defect generation in residential buildings. However, these studies simply investigated the importance of defects by summarizing the frequency of the defects and their costs [15–18]. The defect frequency can be recognized as loss-occurring events and the repair cost of a defect can be interpreted as the weight of loss. This means that if the frequency and cost of defects are considered at the same time, the defect occurrence pattern can be analyzed in a more integrated manner.

This study aims to systematically analyze the patterns and profiles of various defects that occur during the DLP of residential buildings by using the loss distribution approach (LDA).

2. Literature Review

A defect is generally, "a state of a product that does not have the quality or performance that it must normally have. Defects of apartments include cracks, settlements, damage, swelling, leakage, or other flaws due to construction errors. This can result in problems in the safety, function, or aesthetics of the building or facilities" [19,20]. There are two main methods to minimize the loss resulting from defects. The first is to prevent defects in advance. Defects are caused by mutually complex factors throughout the process of design, construction, materials, and maintenance [21]. To prevent them, a fundamental analysis about the causes of defects that have occurred is required. In this respect, existing studies have examined the characteristics of defect generation by reclassifying the defect cases based on various criteria [13,16,22,23]. To prevent defects practically, the fundamental causes should be analyzed based on the types of recognized defects. In this context, various studies on the causes of defects have been conducted [18,24]. In order to identify the cause of the defects that occur in various forms, research has been conducted regarding the classification of the defects behavior [17,25–27]. Moreover, some studies analyzed defect occurrence patterns by thoroughly tracking the causal relations by considering such factors as objects, locations, and work types, as well as direct causes [28,29]. These studies suggested design errors, human errors, financial problems, pressing schedules, materials, and maintenance as the main causes of defects. However, defects are caused by complex nonlinear causal relations between various factors. The mechanism of these complex causes are major obstacles to managing the defect risks because they can change dynamically during time or depend on the project type. In other words, the methods to prevent the construction defects of apartments ultimately have limitations and defects inevitably occur [15,30].

The second method for minimizing the loss from defects is to find rational response measures to defects. Since most industrial products have a warranty system for the product's quality for a certain period, buildings also have a quality assurance system. It is common practice for a construction company, which is the business entity, to take responsibility for the quality assurance of the apartment in the event of defects for a certain period of time [11]. In this regard, existing studies revealed the measures to efficiently operate the warranty system [10,12,31]. Davey et al. (2006) derived the problems during the DLP and emphasized the need for a short-term processing plan to effectively respond to the defects that occur during the handover stage. To address this issue, they proposed measures such as improving the management during the DLP as well as improving the procedures through the cooperation of contractors, consultants, and customers [12]. Hopkin et al. (2016) surveyed UK major stakeholders in regard to the defect frequency to determine the most important types of defects and to identify which defects must be focused on after defects have occurred [32]. However, there are differences in the perspectives about defects that occur during DLP among the major stakeholders that were analyzed [9]. Hence, defect occurrence patterns need to be analyzed in consideration of the DLP.

Efficient defect resolution is difficult due to a fierce clash of opinions and conflicts about the adequacy of the incurred defect repair cost. Therefore, it is necessary to investigate the rationality of the criteria, the scope of the defect judgment, and the detailed criteria for estimating the defect costs. Mills et al. (2009) discussed the characteristics of major defects based on the defect repair costs for buildings constructed between 1977 and 1983 and quantified the effects of the types of contractors and buildings [15]. Furthermore, Hughes et al. (2000) researched the budget range that must be prepared to protect users and to complete the contractor's project by calculating the cost required to resolve the defects [31]. However, these studies were specifically based on an individual analysis without considering other detailed factors such as the tasks, components, and location in an integrated manner. From this background, the present study analyzes the various defect profiles that occur during the DLP to explore reasonable directions for efficient quality control and dispute reconciliation for residential buildings.

3. Materials and Method

The causes of defects that have occurred in residential buildings include: the neglect of supervision; pressing schedules; construction by inexperienced workers; defects in materials; and inadequate inspection. In other words, defects are operation risks mainly caused by humans or process errors. In the financial sector, which already has a high level of risk measurement and management systems, the loss distribution approach (LDA) is a representative method for measuring and managing rising operational risks. LDA is used mainly in sales organizations to assess objective loss estimates through statistical analysis based on existing loss data. As a method that finds the distribution characteristics of operational risks using a vast amount of data generated, the LDA is considered as the most sophisticated and accurate risk measurement method.

This paper establishes a process for measuring defect risks based on the LDA process used to measure the operational risks in the financial field (Figure 1). There are four steps of measurements when measuring the operational risks using the LDA. In step 1, a defect classification system is constructed in 3D. In the existing financial sector, the operating risk frequency distribution and severity distribution are estimated for each of the eight business areas and seven loss cases. That is, 56 areas (8 Business Line (BL) * 7 Loss event type LET) are combined with each other to generate a loss distribution. Then, the cost for responding to the operational risks is calculated using the loss distribution. At this time, the areas are reclassified according to the detailed measurement level and items of the measurement target. In this study, areas were classified based on 11 work types, 7 defect occurrence locations, and 11 defect types (11 * 7 * 11). The data is collected in step 2. The collected data was frequency and severity data corresponding to each cell. In step 3, the frequency and severity distribution of the defect are estimated based on the data. The loss distribution is calculated by combining the two estimated distributions using Monte Carlo simulation. The severity data was scaled according to the size of the apartments and defined as the defect cost versus the total floor area. Finally, in step 4, the risk profiles are organized by the service year based on the calculated loss distribution. Afterwards, the overall analysis is performed.

To estimate the loss frequency and severity distribution, which was step 3 in the LDA measurement process, the distribution of each item is set. For the frequency distribution, which is a discrete distribution, the most representative Poisson distribution is used. In contrast, the severity distribution is a continuous distribution, which is set as a model with a tail distribution with log-normal distribution, Weibull distribution, gamma distribution, and Pareto distribution. To set the severity distribution for each cell in this study, the best fit test was performed for each distribution. Then, the loss distribution was set by performing Monte Carlo simulation 100,000 times using the parameters of the frequency and severity distributions for each cell. After that, the confidence levels of all of the distributions were set ranging from 0% to 100% and the risk level was checked. The loss distribution for each cell was derived through this process and was combined to identify and analyze the defect risk profile of each item classified by the DLP, work type, or space.

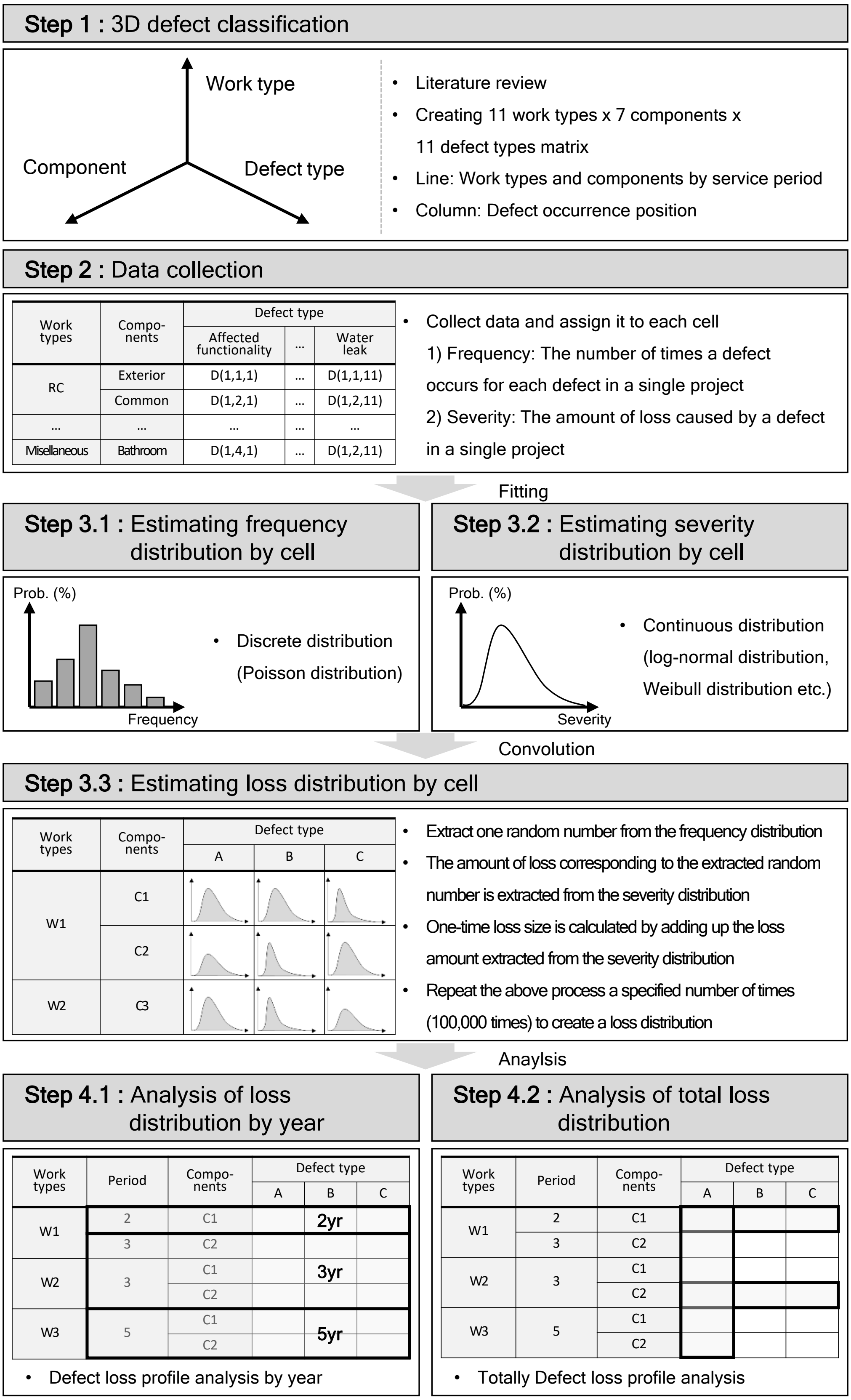

Figure 1. Conducting estimations with the loss distribution approach.

In the process of analyzing defect risks using the LDA, a lack of data may occur in each cell of the 3D defect matrix constructed in accordance with the defect classification system. In this case, the reliability may drop due to the neutrality of the parameter estimates. To prevent this problem, the minimum data corresponding to each cell should be obtained in the setting step of the frequency and severity distributions. Each cell must not be set too broadly or in too much detail. In addition, the range of cells should be classified in consideration of the classification system for the items to be measured. In consideration of this, Table 1 presents the work type-defects liability period, which was classified into 11 categories. These include: reinforced concrete (Rc) (3); Rc (5); Rc (10); masonry (5); finish (2); insulation (3); waterproof (5); mechanical, electrical and plumbing (MEP) (3); door and windows (3); furniture (2); and miscellaneous (3), as suggested by the Ministry of Land, Infrastructure, and Transport of South Korea. The defect locations were classified into seven categories: exterior; common area; garage; hall/corridor; balcony; room/entrance; and bathroom/kitchen. The types of defects were reclassified into 11 categories: affected functionality; broken; corrosion; crack; detachment; incorrect installation; missing task; surface appearance; excess moisture; entrapped water; and water leak (11 work types-liability periods* 7 locations *11 defects). As a result, each cell was classified as shown in Table 2.

Table 1. Defect classification.

Defect Classification	Description	Writer(s)
Affected functionality	Materials/components that must be replaced because its functionality is completely affected. Materials/components that must be repaired but not necessarily replaced because its functionality is partially affected.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013), Rotimi et al. (2015) [16,17,22,24]
Broken	Materials/components physically and forcibly separated into pieces or split.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013), Georgiou et al. (2010), Rotimi et al. (2015), Chong et al. (2006), Chong et al. (2005) [16,17,22–24,27,30]
Corrosion	All defects caused by living beings as molds. Corrosion of metals or the carbonation of concrete.	Macarulla et al. (2013), Rotimi et al. (2015) [22,24]
Crack	Cracks in construction elements.	Forcada et al. (2013), Macarulla et al. (2013), Rotimi et al. (2015), Chong et al. (2005) [16,22,24,30]
Detachment	Materials/components that are not fixed in their position.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013), Rotimi et al. (2015), Chong et al. (2006), Chong et al. (2005) [16,17,22,24,27,30]
Incorrect installation	Materials/components are not well positioned or do not satisfy project specifications or do not have the characteristics they should.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013), Rotimi et al. (2015) [16,17,22,24]
Missingtask	Works that are not completed/done, although the project or specifications are supposed to be collocated or completed/done.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013) [16,17,22]
Surface appearance	Protuberance on a level surface. Opposite effect to a bump. Surface uneven or uniform e.g., in shape or texture, an uneven color, uneven ground, uneven margins, wood with an uneven grain. The result of a collision or abrasion. Surface with a powdery deposit caused by the evaporation of water when there is a certain level of dissolved salts.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013), Rotimi et al. (2015), Chong et al. (2006), Chong et al. (2005) [16,17,22,24]
Excess moisture	Wetness caused by moisture, including rising dampness. Penetration damp and condensation.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013), [16,17,22]
Entrapped water	Water that does not drain.	Macarulla et al. (2013) [22]
Water leak	Defects related to water that seeps through walls, slabs, roofs, etc.	Forcada et al. (2013), Forcada et al. (2013), Macarulla et al. (2013), Chong et al. (2005) [16,17,22,30]

Table 2. Risk matrix of the different types of defects and work types.

Work Types [a] (Liability Period)	Locations [b]	Defects [c]										
		Af	**Br**	**Co**	**Cr**	**De**	**Ii**	**Mt**	**Sa**	**Em**	**Ew**	**Wl**
Rc (3)	Ex	d(1,1,1)	d(1,1,2)	d(1,1,3)	d(1,1,4)	d(1,1,5)	d(1,1,6)	d(1,1,7)	d(1,1,8)	d(1,1,9)	d(1,1,10)	d(1,1,11)
	Ca	d(1,2,1)	d(1,2,2)	d(1,2,3)	d(1,2,4)	d(1,2,5)	d(1,2,6)	d(1,2,7)	d(1,2,8)	d(1,2,9)	d(1,2,10)	d(1,2,11)
	Ga	d(1,3,1)	d(1,3,2)	d(1,3,3)	d(1,3,4)	d(1,3,5)	d(1,3,6)	d(1,3,7)	d(1,3,8)	d(1,3,9)	d(1,3,10)	d(1,3,11)
	Hc	d(1,4,1)	d(1,4,2)	d(1,4,3)	d(1,4,4)	d(1,4,5)	d(1,4,6)	d(1,4,7)	d(1,4,8)	d(1,4,9)	d(1,4,10)	d(1,4,11)
	Ba	d(1,5,1)	d(1,5,2)	d(1,5,3)	d(1,5,4)	d(1,5,5)	d(1,5,6)	d(1,5,7)	d(1,5,8)	d(1,5,9)	d(1,5,10)	d(1,5,11)
	Re	d(1,6,1)	d(1,6,2)	d(1,6,3)	d(1,6,4)	d(1,6,5)	d(1,6,6)	d(1,6,7)	d(1,6,8)	d(1,6,9)	d(1,6,10)	d(1,6,11)
	Bk	d(1,7,1)	d(1,7,2)	d(1,7,3)	d(1,7,4)	d(1,7,5)	d(1,7,6)	d(1,7,7)	d(1,7,8)	d(1,7,9)	d(1,7,10)	d(1,7,11)
Rc (5)	Ex	d(2,1,1)	d(2,1,2)	d(2,1,3)	d(2,1,4)	d(2,1,5)	d(2,1,6)	d(2,1,7)	d(2,1,8)	d(2,1,9)	d(2,1,10)	d(2,1,11)
	Ca	d(2,2,1)	d(2,2,2)	d(2,2,3)	d(2,2,4)	d(2,2,5)	d(2,2,6)	d(2,2,7)	d(2,2,8)	d(2,2,9)	d(2,2,10)	d(2,2,11)
	Ga	d(2,3,1)	d(2,3,2)	d(2,3,3)	d(2,3,4)	d(2,3,5)	d(2,3,6)	d(2,3,7)	d(2,3,8)	d(2,3,9)	d(2,3,10)	d(2,3,11)
	Hc	d(2,4,1)	d(2,4,2)	d(2,4,3)	d(2,4,4)	d(2,4,5)	d(2,4,6)	d(2,4,7)	d(2,4,8)	d(2,4,9)	d(2,4,10)	d(2,4,11)
	Ba	d(2,5,1)	d(2,5,2)	d(2,5,3)	d(2,5,4)	d(2,5,5)	d(2,5,6)	d(2,5,7)	d(2,5,8)	d(2,5,9)	d(2,5,10)	d(2,5,11)
	Re	d(2,6,1)	d(2,6,2)	d(2,6,3)	d(2,6,4)	d(2,6,5)	d(2,6,6)	d(2,6,7)	d(2,6,8)	d(2,6,9)	d(2,6,10)	d(2,6,11)
	Bk	d(2,7,1)	d(2,7,2)	d(2,7,3)	d(2,7,4)	d(2,7,5)	d(2,7,6)	d(2,7,7)	d(2,7,8)	d(2,7,9)	d(2,7,10)	d(2,7,11)
Rc (10)	Ex	d(3,1,1)	d(3,1,2)	d(3,1,3)	d(3,1,4)	d(3,1,5)	d(3,1,6)	d(3,1,7)	d(3,1,8)	d(3,1,9)	d(3,1,10)	d(3,1,11)
	Ca	d(3,2,1)	d(3,2,2)	d(3,2,3)	d(3,2,4)	d(3,2,5)	d(3,2,6)	d(3,2,7)	d(3,2,8)	d(3,2,9)	d(3,2,10)	d(3,2,11)
	Ga	d(3,3,1)	d(3,3,2)	d(3,3,3)	d(3,3,4)	d(3,3,5)	d(3,3,6)	d(3,3,7)	d(3,3,8)	d(3,3,9)	d(3,3,10)	d(3,3,11)
	Hc	d(3,4,1)	d(3,4,2)	d(3,4,3)	d(3,4,4)	d(3,4,5)	d(3,4,6)	d(3,4,7)	d(3,4,8)	d(3,4,9)	d(3,4,10)	d(3,4,11)
	Ba	d(3,5,1)	d(3,5,2)	d(3,5,3)	d(3,5,4)	d(3,5,5)	d(3,5,6)	d(3,5,7)	d(3,5,8)	d(3,5,9)	d(3,5,10)	d(3,5,11)
	Re	d(3,6,1)	d(3,6,2)	d(3,6,3)	d(3,6,4)	d(3,6,5)	d(3,6,6)	d(3,6,7)	d(3,6,8)	d(3,6,9)	d(3,6,10)	d(3,6,11)
	Bk	d(3,7,1)	d(3,7,2)	d(3,7,3)	d(3,7,4)	d(3,7,5)	d(3,7,6)	d(3,7,7)	d(3,7,8)	d(3,7,9)	d(3,7,10)	d(3,7,11)
Ma (5)	Ex	d(4,1,1)	d(4,1,2)	d(4,1,3)	d(4,1,4)	d(4,1,5)	d(4,1,6)	d(4,1,7)	d(4,1,8)	d(4,1,9)	d(4,1,10)	d(4,1,11)
	Ca	d(4,2,1)	d(4,2,2)	d(4,2,3)	d(4,2,4)	d(4,2,5)	d(4,2,6)	d(4,2,7)	d(4,2,8)	d(4,2,9)	d(4,2,10)	d(4,2,11)
	Ga	d(4,3,1)	d(4,3,2)	d(4,3,3)	d(4,3,4)	d(4,3,5)	d(4,3,6)	d(4,3,7)	d(4,3,8)	d(4,3,9)	d(4,3,10)	d(4,3,11)
	Hc	d(4,4,1)	d(4,4,2)	d(4,4,3)	d(4,4,4)	d(4,4,5)	d(4,4,6)	d(4,4,7)	d(4,4,8)	d(4,4,9)	d(4,4,10)	d(4,4,11)
	Ba	d(4,5,1)	d(4,5,2)	d(4,5,3)	d(4,5,4)	d(4,5,5)	d(4,5,6)	d(4,5,7)	d(4,5,8)	d(4,5,9)	d(4,5,10)	d(4,5,11)
	Re	d(4,6,1)	d(4,6,2)	d(4,6,3)	d(4,6,4)	d(4,6,5)	d(4,6,6)	d(4,6,7)	d(4,6,8)	d(4,6,9)	d(4,6,10)	d(4,6,11)
	Bk	d(4,7,1)	d(4,7,2)	d(4,7,3)	d(4,7,4)	d(4,7,5)	d(4,7,6)	d(4,7,7)	d(4,7,8)	d(4,7,9)	d(4,7,10)	d(4,7,11)
Fi (2)	Ex	d(5,1,1)	d(5,1,2)	d(5,1,3)	d(5,1,4)	d(5,1,5)	d(5,1,6)	d(5,1,7)	d(5,1,8)	d(5,1,9)	d(5,1,10)	d(5,1,11)
	Ca	d(5,2,1)	d(5,2,2)	d(5,2,3)	d(5,2,4)	d(5,2,5)	d(5,2,6)	d(5,2,7)	d(5,2,8)	d(5,2,9)	d(5,2,10)	d(5,2,11)
	Ga	d(5,3,1)	d(5,3,2)	d(5,3,3)	d(5,3,4)	d(5,3,5)	d(5,3,6)	d(5,3,7)	d(5,3,8)	d(5,3,9)	d(5,3,10)	d(5,3,11)
	Hc	d(5,4,1)	d(5,4,2)	d(5,4,3)	d(5,4,4)	d(5,4,5)	d(5,4,6)	d(5,4,7)	d(5,4,8)	d(5,4,9)	d(5,4,10)	d(5,4,11)
	Ba	d(5,5,1)	d(5,5,2)	d(5,5,3)	d(5,5,4)	d(5,5,5)	d(5,5,6)	d(5,5,7)	d(5,5,8)	d(5,5,9)	d(5,5,10)	d(5,5,11)
	Re	d(5,6,1)	d(5,6,2)	d(5,6,3)	d(5,6,4)	d(5,6,5)	d(5,6,6)	d(5,6,7)	d(5,6,8)	d(5,6,9)	d(5,6,10)	d(5,6,11)
	Bk	d(5,7,1)	d(5,7,2)	d(5,7,3)	d(5,7,4)	d(5,7,5)	d(5,7,6)	d(5,7,7)	d(5,7,8)	d(5,7,9)	d(5,7,10)	d(5,7,11)
In (3)	Ex	d(6,1,1)	d(6,1,2)	d(6,1,3)	d(6,1,4)	d(6,1,5)	d(6,1,6)	d(6,1,7)	d(6,1,8)	d(6,1,9)	d(6,1,10)	d(6,1,11)
	Ca	d(6,2,1)	d(6,2,2)	d(6,2,3)	d(6,2,4)	d(6,2,5)	d(6,2,6)	d(6,2,7)	d(6,2,8)	d(6,2,9)	d(6,2,10)	d(6,2,11)
	Ga	d(6,3,1)	d(6,3,2)	d(6,3,3)	d(6,3,4)	d(6,3,5)	d(6,3,6)	d(6,3,7)	d(6,3,8)	d(6,3,9)	d(6,3,10)	d(6,3,11)
	Hc	d(6,4,1)	d(6,4,2)	d(6,4,3)	d(6,4,4)	d(6,4,5)	d(6,4,6)	d(6,4,7)	d(6,4,8)	d(6,4,9)	d(6,4,10)	d(6,4,11)
	Ba	d(6,5,1)	d(6,5,2)	d(6,5,3)	d(6,5,4)	d(6,5,5)	d(6,5,6)	d(6,5,7)	d(6,5,8)	d(6,5,9)	d(6,5,10)	d(6,5,11)
	Re	d(6,6,1)	d(6,6,2)	d(6,6,3)	d(6,6,4)	d(6,6,5)	d(6,6,6)	d(6,6,7)	d(6,6,8)	d(6,6,9)	d(6,6,10)	d(6,6,11)
	Bk	d(6,7,1)	d(6,7,2)	d(6,7,3)	d(6,7,4)	d(6,7,5)	d(6,7,6)	d(6,7,7)	d(6,7,8)	d(6,7,9)	d(6,7,10)	d(6,7,11)
Wa (5)	Ex	d(7,1,1)	d(7,1,2)	d(7,1,3)	d(7,1,4)	d(7,1,5)	d(7,1,6)	d(7,1,7)	d(7,1,8)	d(7,1,9)	d(7,1,10)	d(7,1,11)
	Ca	d(7,2,1)	d(7,2,2)	d(7,2,3)	d(7,2,4)	d(7,2,5)	d(7,2,6)	d(7,2,7)	d(7,2,8)	d(7,2,9)	d(7,2,10)	d(7,2,11)
	Ga	d(7,3,1)	d(7,3,2)	d(7,3,3)	d(7,3,4)	d(7,3,5)	d(7,3,6)	d(7,3,7)	d(7,3,8)	d(7,3,9)	d(7,3,10)	d(7,3,11)
	Hc	d(7,4,1)	d(7,4,2)	d(7,4,3)	d(7,4,4)	d(7,4,5)	d(7,4,6)	d(7,4,7)	d(7,4,8)	d(7,4,9)	d(7,4,10)	d(7,4,11)
	Ba	d(7,5,1)	d(7,5,2)	d(7,5,3)	d(7,5,4)	d(7,5,5)	d(7,5,6)	d(7,5,7)	d(7,5,8)	d(7,5,9)	d(7,5,10)	d(7,5,11)
	Re	d(7,6,1)	d(7,6,2)	d(7,6,3)	d(7,6,4)	d(7,6,5)	d(7,6,6)	d(7,6,7)	d(7,6,8)	d(7,6,9)	d(7,6,10)	d(7,6,11)
	Bk	d(7,7,1)	d(7,7,2)	d(7,7,3)	d(7,7,4)	d(7,7,5)	d(7,7,6)	d(7,7,7)	d(7,7,8)	d(7,7,9)	d(7,7,10)	d(7,7,11)
Me (3)	Ex	d(8,1,1)	d(8,1,2)	d(8,1,3)	d(8,1,4)	d(8,1,5)	d(8,1,6)	d(8,1,7)	d(8,1,8)	d(8,1,9)	d(8,1,10)	d(8,1,11)
	Ca	d(8,2,1)	d(8,2,2)	d(8,2,3)	d(8,2,4)	d(8,2,5)	d(8,2,6)	d(8,2,7)	d(8,2,8)	d(8,2,9)	d(8,2,10)	d(8,2,11)
	Ga	d(8,3,1)	d(8,3,2)	d(8,3,3)	d(8,3,4)	d(8,3,5)	d(8,3,6)	d(8,3,7)	d(8,3,8)	d(8,3,9)	d(8,3,10)	d(8,3,11)
	Hc	d(8,4,1)	d(8,4,2)	d(8,4,3)	d(8,4,4)	d(8,4,5)	d(8,4,6)	d(8,4,7)	d(8,4,8)	d(8,4,9)	d(8,4,10)	d(8,4,11)
	Ba	d(8,5,1)	d(8,5,2)	d(8,5,3)	d(8,5,4)	d(8,5,5)	d(8,5,6)	d(8,5,7)	d(8,5,8)	d(8,5,9)	d(8,5,10)	d(8,5,11)
	Re	d(8,6,1)	d(8,6,2)	d(8,6,3)	d(8,6,4)	d(8,6,5)	d(8,6,6)	d(8,6,7)	d(8,6,8)	d(8,6,9)	d(8,6,10)	d(8,6,11)
	Bk	d(8,7,1)	d(8,7,2)	d(8,7,3)	d(8,7,4)	d(8,7,5)	d(8,7,6)	d(8,7,7)	d(8,7,8)	d(8,7,9)	d(8,7,10)	d(8,7,11)
Dw (3)	Ex	d(9,1,1)	d(9,1,2)	d(9,1,3)	d(9,1,4)	d(9,1,5)	d(9,1,6)	d(9,1,7)	d(9,1,8)	d(9,1,9)	d(9,1,10)	d(9,1,11)
	Ca	d(9,2,1)	d(9,2,2)	d(9,2,3)	d(9,2,4)	d(9,2,5)	d(9,2,6)	d(9,2,7)	d(9,2,8)	d(9,2,9)	d(9,2,10)	d(9,2,11)
	Ga	d(9,3,1)	d(9,3,2)	d(9,3,3)	d(9,3,4)	d(9,3,5)	d(9,3,6)	d(9,3,7)	d(9,3,8)	d(9,3,9)	d(9,3,10)	d(9,3,11)
	Hc	d(9,4,1)	d(9,4,2)	d(9,4,3)	d(9,4,4)	d(9,4,5)	d(9,4,6)	d(9,4,7)	d(9,4,8)	d(9,4,9)	d(9,4,10)	d(9,4,11)
	Ba	d(9,5,1)	d(9,5,2)	d(9,5,3)	d(9,5,4)	d(9,5,5)	d(9,5,6)	d(9,5,7)	d(9,5,8)	d(9,5,9)	d(9,5,10)	d(9,5,11)
	Re	d(9,6,1)	d(9,6,2)	d(9,6,3)	d(9,6,4)	d(9,6,5)	d(9,6,6)	d(9,6,7)	d(9,6,8)	d(9,6,9)	d(9,6,10)	d(9,6,11)
	Bk	d(9,7,1)	d(9,7,2)	d(9,7,3)	d(9,7,4)	d(9,7,5)	d(9,7,6)	d(9,7,7)	d(9,7,8)	d(9,7,9)	d(9,7,10)	d(9,7,11)
Fu (2)	Ex	d(10,1,1)	d(10,1,2)	d(10,1,3)	d(10,1,4)	d(10,1,5)	d(10,1,6)	d(10,1,7)	d(10,1,8)	d(10,1,9)	d(10,1,10)	d(10,1,11)
	Ca	d(10,2,1)	d(10,2,2)	d(10,2,3)	d(10,2,4)	d(10,2,5)	d(10,2,6)	d(10,2,7)	d(10,2,8)	d(10,2,9)	d(10,2,10)	d(10,2,11)
	Ga	d(10,3,1)	d(10,3,2)	d(10,3,3)	d(10,3,4)	d(10,3,5)	d(10,3,6)	d(10,3,7)	d(10,3,8)	d(10,3,9)	d(10,3,10)	d(10,3,11)
	Hc	d(10,4,1)	d(10,4,2)	d(10,4,3)	d(10,4,4)	d(10,4,5)	d(10,4,6)	d(10,4,7)	d(10,4,8)	d(10,4,9)	d(10,4,10)	d(10,4,11)
	Ba	d(10,5,1)	d(10,5,2)	d(10,5,3)	d(10,5,4)	d(10,5,5)	d(10,5,6)	d(10,5,7)	d(10,5,8)	d(10,5,9)	d(10,5,10)	d(10,5,11)
	Re	d(10,6,1)	d(10,6,2)	d(10,6,3)	d(10,6,4)	d(10,6,5)	d(10,6,6)	d(10,6,7)	d(10,6,8)	d(10,6,9)	d(10,6,10)	d(10,6,11)
	Bk	d(10,7,1)	d(10,7,2)	d(10,7,3)	d(10,7,4)	d(10,7,5)	d(10,7,6)	d(10,7,7)	d(10,7,8)	d(10,7,9)	d(10,7,10)	d(10,7,11)

Table 2. *Cont.*

Work Types [a] (Liability Period)	Locations [b]	Defects [c]										
		Af	Br	Co	Cr	De	Ii	Mt	Sa	Em	Ew	Wl
Mi (3)	Ex	d(11,1,1)	d(11,1,2)	d(11,1,3)	d(11,1,4)	d(11,1,5)	d(11,1,6)	d(11,1,7)	d(11,1,8)	d(11,1,9)	d(11,1,10)	d(11,1,11)
	Ca	d(11,2,1)	d(11,2,2)	d(11,2,3)	d(11,2,4)	d(11,2,5)	d(11,2,6)	d(11,2,7)	d(11,2,8)	d(11,2,9)	d(11,2,10)	d(11,2,11)
	Ga	d(11,3,1)	d(11,3,2)	d(11,3,3)	d(11,3,4)	d(11,3,5)	d(11,3,6)	d(11,3,7)	d(11,3,8)	d(11,3,9)	d(11,3,10)	d(11,3,11)
	Hc	d(11,4,1)	d(11,4,2)	d(11,4,3)	d(11,4,4)	d(11,4,5)	d(11,4,6)	d(11,4,7)	d(11,4,8)	d(11,4,9)	d(11,4,10)	d(11,4,11)
	Ba	d(11,5,1)	d(11,5,2)	d(11,5,3)	d(11,5,4)	d(11,5,5)	d(11,5,6)	d(11,5,7)	d(11,5,8)	d(11,5,9)	d(11,5,10)	d(11,5,11)
	Re	d(11,6,1)	d(11,6,2)	d(11,6,3)	d(11,6,4)	d(11,6,5)	d(11,6,6)	d(11,6,7)	d(11,6,8)	d(11,6,9)	d(11,6,10)	d(11,6,11)
	Bk	d(11,7,1)	d(11,7,2)	d(11,7,3)	d(11,7,4)	d(11,7,5)	d(11,7,6)	d(11,7,7)	d(11,7,8)	d(11,7,9)	d(11,7,10)	d(11,7,11)

[a] Rc = reinforced concrete; Ma = masonry; Fi = finish; In = insulation; Wa = waterproof; Me = MEP; Dw = door and windows; Fu = furniture; Mi = miscellaneous. [b] Ex = exterior; Ca = common area; Ga = garage; Hc = hall/corridor; Ba = balcony; Re = room/entrance; Bk = bathroom/kitchen. [c] Af = affected functionality; Br = broken; Co = corrosion; Cr = crack; De = detachment; Ii = incorrect installation; Mt = missing task; Sa = surface appearance; Em = excess moisture; Ew = entrapped water; Wl = water leak.

4. Analysis

4.1. Data Collection and Setting the 3D Defect Classification

This study has analyzed 16,108 defects from 133 residential buildings where defect disputes occurred in South Korea between 2008 and 2018. As shown by the frequency of each defect type in Table 3, cracks (28.50%) were the most frequent defect type, followed by missing tasks (14.23%), detachments (10.91%), affected functionalities (9.87%), and surface appearance (9.86%). Severity data was analyzed by correcting the defect costs by the gross floor area (GFA). Water leaks (30.30%) had the highest defect cost. Incorrect installation (27.18%), surface appearance (13.86%), missing tasks (11.19%), and cracks (6.16%) required relatively high defect costs.

Table 3. Defect frequency and the cost for each defect type.

Category	Defect Frequency (Number)	Defect Frequency Rate (%)	Defect Cost/G.F.A ($/m^2)	Defect Cost/G.F.A Rate (%)
Affected functionality	11.44	9.87	0.46	0.78
Broken	4.46	3.85	0.54	0.91
Corrosion	3.34	2.88	1.33	2.25
Crack	33.02	28.50	3.64	6.16
Detachment	12.64	10.91	2.92	4.94
Incorrect installation	9.16	7.91	16.07	27.18
Missing task	16.49	14.23	6.61	11.19
Surface appearance	11.42	9.86	8.20	13.86
Excess moisture	1.89	1.63	0.71	1.20
Entrapped water	3.22	2.78	0.72	1.22
Water leak	8.77	7.57	17.91	30.30
Total	115.85	100.00	59.11	100.00

Note: unit is number of projects.

4.2. Estimating Loss Distributions by the Cell

Each country has a warranty system to protect consumers from damage due to defects after completion of the construction and occupancy. The warranty system of South Korea requires the contractor to deposit 3% of the total construction cost for repairing defects to the public agency after completion. When defects occur, the occupants use the deposit for any necessary repairs for the DLP for each facility that was constricted. The contractor is responsible for the repair of the defect even if the repair cost exceeds the deposit. On the other hand, if the repair cost is less than the deposit, afterwards, the balance is returned to the contractor. In view of this, the profile of the defect risk for each DLP was analyzed and the step-by-step management measures are derived.

In this study, the frequency and severity distribution of each cell in the above risk matrix was set based on the classified data. The Poisson distribution was set as the frequency distribution because it is most widely used in discrete distribution. Furthermore, among the continuous distributions, including log-normal distribution, Weibull distribution, gamma distribution, and Pareto distribution, the distribution that has the best fit was set for the severity distribution of each cell. Then, the defect loss distribution of each cell was derived by performing a Monte Carlo simulation based on these frequency and severity distributions while considering the DLP of each cell.

First, a general analysis on the defect loss distribution was performed. Figure 2 illustrates the scatter chart for each cell based on the results of the frequency and severity distributions. Scatter chart analysis can be used to suggest defects risk profile analysis and application method. The finish work has a very high defect frequency by the missing task of public locations and was a typical case of HFLS (high-frequency, low-severity). The defects of finish work of buildings in public locations showed a high likelihood due to differences between the design drawings and the actual work or poor construction.

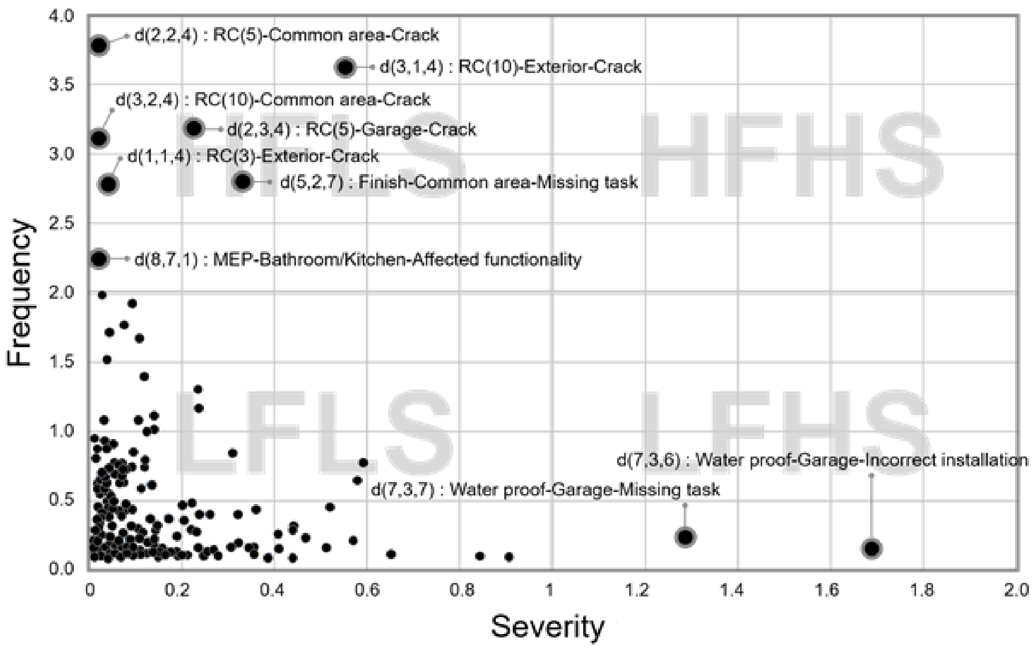

Figure 2. Frequency and severity scatter chart of the defects.

The RC work had a very high defect frequency due to cracks in public locations, which was found to be a typical case of HFLS (high-frequency, low-severity). Cracks in structures in public locations, such as the exterior, garage, and common areas, are natural phenomenon caused by aging. However, cracks can be regarded as serious defects. If cracks are not repaired, external factors accelerate the deterioration and aging of the defective parts and lead to continuous defects.

By contrast, the MEP work showed a very high defect frequency in private locations and was found to be a typical case of HFLS. Furthermore, the MEP work showed a high loss of malfunction defects. This defect is caused by a combination of construction factors such as missing equipment or modified construction, and mechanical factors such as poor product operation.

The waterproof work showed a very high defect cost in public locations, which was a typical case of LFHS (low-frequency high-severity). In particular, poor waterproof finishing in places exposed to the outside, such as underground parking lots and rooftops, can cause serious damage to the structure; thus, responsible quality control is required on the part of the contractor.

Next, a detailed analysis was performed of the defect loss distribution by the DLP. Table 4 lists the cells with 10 of the highest average values of the defect loss distribution for defects occurring within two years of the DLP. Figure 3 shows a scatter chart for the average values of the frequency/severity distributions for each cell that occurred within two years of the DLP. For the finish work, the losses of missing tasks, incorrect installations, and detachments occurred at all locations including shared/exclusive spaces. These defects are considered to have occurred due to the neglect of supervision at the site as well as work by inexperienced workers. Furthermore, the frequency of occurrence seems to be high because it is easier to recognize defects. Table 5 outlines the characteristics of the defect risks by defect type, location, and work type for defects occurring within two years of the DLP. This presents management measures by phase including the design, construction, handover, post-handover, and occupancy phase. Defects for finish work, which occur in private spaces, had higher defect losses due to problems associated with the contractor's management rather than misuse by the occupants. Furthermore, the finish process should be completed before the handover phase because the defects can be easily seen by the occupants or contractor.

Table 4. Ranking the defects loss occurring within two years of the defect liability period (DLP).

Ranking	Work Types	Location	Defects	Average
1	Finish	Bathroom/Kitchen	Incorrect installation	0.370
2	Finish	Hall/Corridor	Missing task	0.309
3	Finish	Bathroom/Kitchen	Missing task	0.279
4	Finish	Room/Entrance	Incorrect installation	0.208
5	Finish	Room/Entrance	Detachment	0.183
6	Finish	Room/Entrance	Broken	0.181
7	Finish	Bathroom/Kitchen	Detachment	0.174
8	Finish	Hall/Corridor	Incorrect installation	0.134
9	Finish	Common area	Missing task	0.131
10	Finish	Garage	Missing task	0.125

Note: average means the mean value of loss distribution statistics.

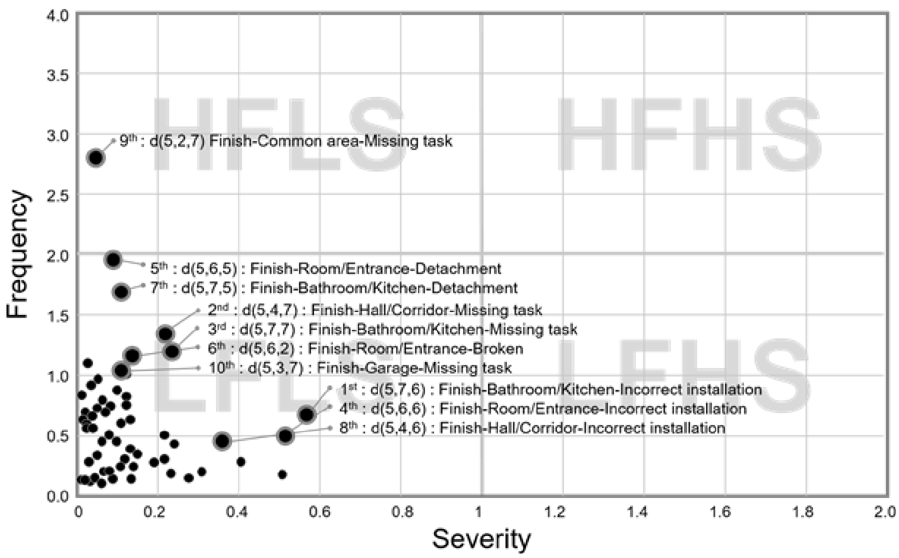

Figure 3. Frequency and severity scatter chart of a defect occurring within two years of the DLP.

Table 5. Defect risk management strategies occurring within two years of the DLP.

Risk Zone	Defect Characteristics		Defect Risk Management Strategies
	Cell No	Phase	
HFLS	d(5,2,7)	Construction	Construction of components is required after disassembly, because incorrect installations and missing tasks appear as major defects. Thorough management during construction is required because of a serious defect that prevents the building from performing its function and role at all, or demolishing is required simultaneously with construction depending on the field situation.
LFLS	d(5,7,6) d(5,4,7) d(5,7,7) d(5,6,6) d(5,4,6) d(5,3,7)		
LFLS	d(5,6,5) d(5,6,2) d(5,7,5)	Handover	Defects such as detachment and breakage need to be reviewed through visual inspection, along with careful management of the construction status by reviewing the design documents and design change documents during the inspection of use.

Table 6 lists the cells with 12 of the highest average values of the defect loss distribution for defects occurring after 2 years and before 3 years of the DLP. Figure 4 shows the scatter chart for the average frequency/severity distributions for each cell for defects that occurred after 2 years and before 3 years of the DLP. This analysis confirmed that the RC work was associated with relatively high losses due to cracks, surface appearance, and detachment defects in the exterior. It is a consequence of the exterior walls that are exposed to outside conditions and have a higher probability of occurrence of defects due to external factors such as typhoons, daily/seasonal temperature and humidity variations, sun exposure, etc. MEP work has a high loss of missing tasks and affected functionality defects. These defects occur during a series of construction of various components within the building because some elements are not constructed or due to poor connection between components. Furthermore, they can also be caused by the malfunction or unconformities of the product itself. In practice, MEP operations often occur in the early stages because they are easily recognizable by the user. However, the reason why it is significantly higher within three years compared to other periods is that the proportion of other defects falls significantly within the three years.

Table 6. Ranking of the defect loss occurring within three years of the DLP.

Ranking	Work Types	Location	Defects	Average
1	RC	Exterior	Crack	0.923
2	RC	Exterior	Surface appearance	0.428
3	RC	Exterior	Detachment	0.138
4	MEP	Common area	Missing task	0.134
5	RC	Exterior	Water leak	0.111
6	MEP	Balcony	Missing task	0.081
7	MEP	Bathroom/Kitchen	Missing task	0.076
8	Insulation	Bathroom/Kitchen	Incorrect installation	0.066
9	Insulation	Room/Entrance	Excess moisture	0.062
10	Door and Windows	Room/Entrance	Affected functionality	0.060
11	MEP	Bathroom/Kitchen	Affected functionality	0.057
12	MEP	Entrance	Affected functionality	0.056

Note: average means the mean value of loss distribution statistics.

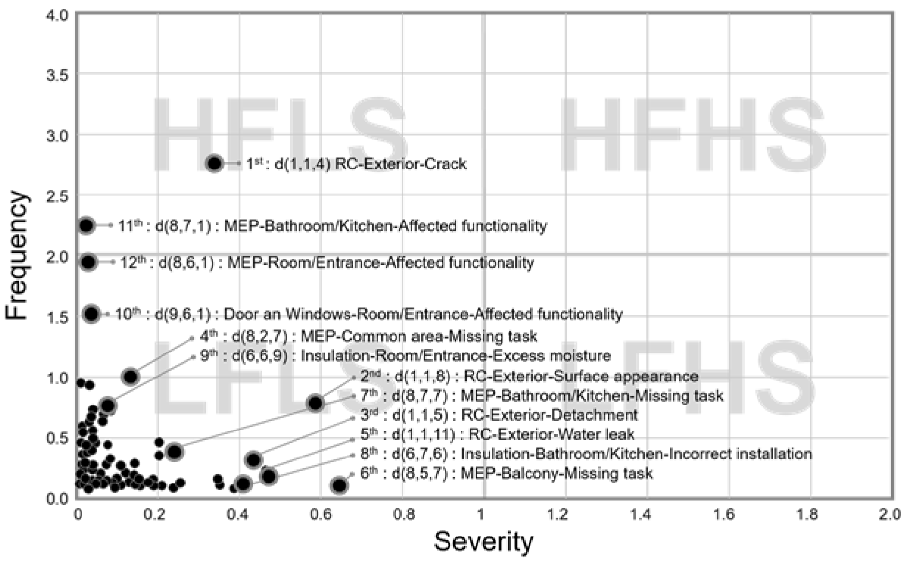

Figure 4. Frequency and severity scatter chart of a defect occurring within three years of the DLP.

These affected functionality defects also caused a high loss in doors and windows. Along with the MEP work, this is likely caused by defective or damaged furniture or windows installed in exclusive spaces. Focusing on the highest loss in doors and windows is not the defects that the user is responsible for.

Defects caused by poor quality insulation are also high. In the event of defects in the insulation work, the area was first removed and the area was constructed again.

If a crack or damage occurs in a structure at a public location such as an outer wall, a series of defects such as poor surface appearance or water leakage defects may occur. As a result, an immediate response is necessary to reduce the defect loss. Moreover, high defect losses caused by incorrect installations and missing tasks can be minimized through management and supervision in the construction phase. The affected functionality defect of MEP construction and the excess moisture defect of insulation work are caused by complex factors in all life cycles of construction. To prevent these in advance, the potential defects need to be examined from the design phase (Table 7).

Table 7. Defect risk management strategies occurring within three years of the DLP.

Risk Zone	Defect Characteristics		Defect Risk Management Strategies
	Cell No	Phase	
HFLS	d(1,1,4)	Post-Handover and Occupancy	Secondary defects can occur from cracks and damage in the main structure. An early response at the beginning of a defect is effective to reduce serial losses.
LFHS	d(1,1,8) d(1,1,5) d(1,1,11)		
LFLS	d(8,2,7) d(8,5,7) d(8,7,7) d(6,7,6)	Construction	Thorough management and supervision in the construction phase is required to reduce the losses of incorrect installations and missing tasks.
LFLS	d(6,6,9) d(9,6,1) d(8,7,1) d(8,6,1)	Design, Construction, and Handover	Management measures are required, such as constructability review in the design phase of MEP work and close collaboration between work types in the construction phase. Water leakage due to poor insulation work has a significant effect on the satisfaction of occupants, causing severe inconvenience. Hence, continuous management measures such as thorough design, appropriate method, and proper material selection are required.

Table 8 lists the cells with high average values for the defect loss distribution for defects that occurred after 3 years and before 5 years of the DLP. Figure 5 shows a scatter chart of the average values of the frequency/severity distributions for each cell for the defects that occurred after 3 years and before 5 years of the DLP. In particular, the RC work had relatively high losses of crack and water leak defects in the common area and garage. This is different from the pattern of 3 years of the DLP with a high loss of crack defects in the RC work due to internal and external factors. The structure of the apartments consists of concrete, which inevitably causes cracks because concrete is a construction material composite, made of different elements. In particular, cracks in underground parking lots cause water leaks, which can significantly affect the durability of the building. Therefore, a strategy is required to prevent defects that may occur in the future through early detection of potential defect sites through frame inspections during the finish work (Table 9).

Table 8. Ranking of the defects loss occurring within five years of the DLP.

Ranking	Work Types	Location	Defects	Average
1	RC	Garage	Crack	0.706
2	Water proof	Garage	Incorrect installation	0.319
3	Water proof	Garage	Missing task	0.307
4	RC	Exterior	Crack	0.167
5	Water proof	Balcony	Water leak	0.136
6	RC	Garage	Water leak	0.135
7	RC	Balcony	Crack	0.120
8	RC	Garage	Surface appearance	0.103
9	RC	Garage	Incorrect installation	0.101
10	Water proof	Exterior	Water leak	0.086
11	RC	Common area	Crack	0.073

Note: average means the mean value of loss distribution statistics.

Waterproof work featured high losses of incorrect installations and missing task defects in the garage. This appears to be linked to the crack and water leak defects in the RC work. The incorrect installations and missing tasks of waterproof work causes water tightness and surface defects. In reverse order, when cracks are generated, the vicious circle of water leaks, corrosion of the reinforcement materials, and crack enlargement are repeated. Thus, thorough management is required to reduce incorrect installation of waterproof work with LFHS characteristics. This is because such defects are caused by poor construction. Water leak defects in waterproof work with LFLS characteristics too are caused by poor construction. However, it is also caused by other defects such as cracks. It is related to places affected by external factors such as exterior or balcony. Therefore, an immediate response to the defect in the early stage is required to reduce the defect losses (Table 9).

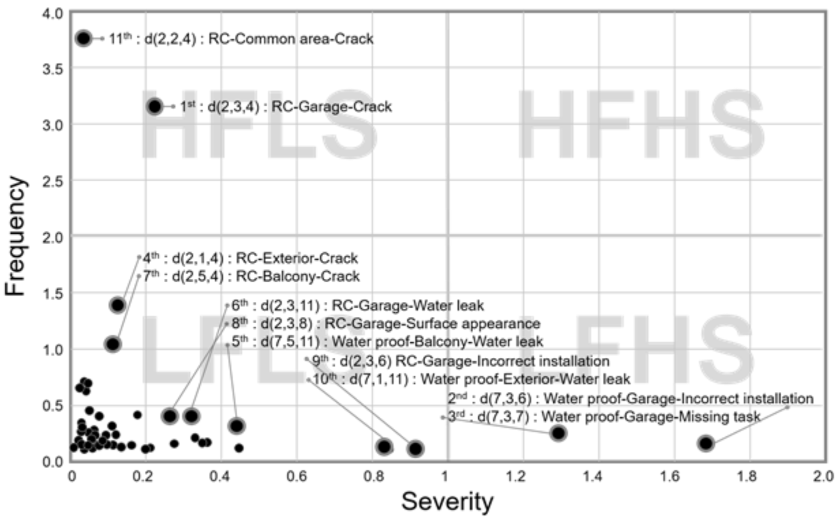

Figure 5. Frequency and severity scatter chart of a defect occurring within five years of the DLP.

Table 9. Defect risk management strategies occurring within five years of the DLP.

Risk Zone	Defect Characteristics		Defect Risk Management
	Cell No	Phase	Strategies
HFLS	d(2,3,4) d(2,2,4)	Handover, Post-Handover and Occupancy	Cracks/damage occurs in structures such as underground parking lots. RC work of the underground parking lot can be visually inspected. Thus, a strategy to discover potential defects early through thorough defect inspection in the handover phase is required. Crack defect can lead to a series of other defects such as surface defects and water leakage. Therefore, an immediate response in the early stage of a defect is required.
LFLS	d(2,1,4) d(2,3,11) d(2,5,4) d(2,3,8) d(2,3,6)		
LFLS	d(7,5,11) d(7,1,11)	Post-Handover and Occupancy	Crack/water leakage occurs in parts that have contact with the outside environment. This can lead to other defects such as crack enlargement and reinforcement corrosion. Thus, an early response to the defect is critical to reduce the defect losses.
LFHS	d(7,3,6) d(7,3,7)	Construction	Reconstruction is required because incorrect installation and missing tasks appear as the main defects.

Table 10 lists the cells with high average values of the defect loss distribution for defects that occurred after 5 years and before 10 years of the DLP. Figure 6 illustrates a scatter chart of the average values of the frequency/severity distributions for each cell for defects that occurred after 5 years and before 10 years of the DLP. The analysis results show that in the case of the RC work, various defects including crack, surface appearance, water leakage, detachment, and corrosion occurred in various exterior and interior parts such as halls/corridors and the garage. In particular, the crack defect losses were high for the outer wall. This is because the RC work, which is the largest type of construction work, has additional accessory processes and repair work in high places. These crack defects caused high losses in the halls/corridors, the garage, common areas, as well as the outer walls. Since this is a defect due to the negligence of the business entity, the business entity should perform the repair. Crack defects must be repaired because they are serious issues in the durability and functionality of the structure. Cracks on concrete generally define the length of width required for repair cracks as 0.3 to 0.4 mm, depending on structure, component, defects, etc. Even if the width of the crack is less than 0.3 mm, problems can occur from the perspective of the structure's function, safety, and durability as rebars are corroded and cracks spread due to penetration of rainwater.

Table 10. Ranking of the defects loss occurring within ten years of the DLP.

Ranking	Work Types	Location	Defects	Average
1	RC	Exterior	Crack	2.029
2	RC	Exterior	Surface appearance	0.262
3	RC	Hall/corridor	Crack	0.137
4	RC	Exterior	Water leak	0.123
5	RC	Garage	Crack	0.078
6	RC	Garage	Water leak	0.066
7	RC	Common area	Crack	0.060
8	RC	Exterior	Detachment	0.045
9	RC	Hall/corridor	Water leak	0.039
10	RC	Exterior	Corrosion	0.032

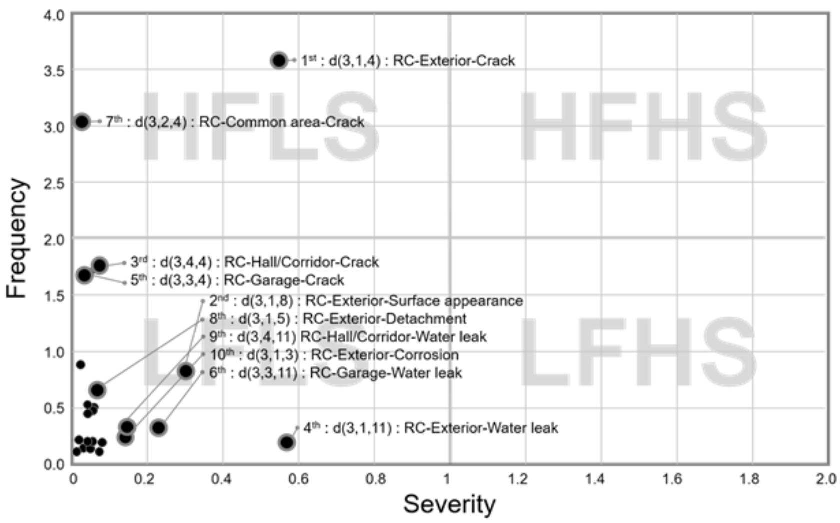

Figure 6. Frequency and severity scatter chart of a defect occurring within ten years of the DLP.

Due to the presence of a crack defect, various defects generated in RC work are due to errors made by the contractor such as inaccurate arrangements of reinforcements, poor curing after casting, and cold joints. Therefore, if the cause of the defects is clearly by the contractor, the contractor must perform the repair work even if the warranty period of the item has expired (Table 11).

Table 11. Defect risk management strategies occurring within ten years of the DLP.

Risk Zone	Defect Characteristics		Defect Risk Management
	Cell No	Phase	Strategies
HFLS	d(3,1,4) d(3,2,4)	Construction	Crack/damage occurs in the structure. Losses must be minimized through thorough management in the construction phase rather than response/repair after completion. Even if the defect liability period has expired, the business entity must take responsibility for defects that occurred a long time before the end of the durable period of the component (Only if the contractor has the cause of the defect).
LFLS	d(3,1,8) d(3,1,5) d(3,1,11) d(3,1,3) d(3,3,4) d(3,3,11) d(3,4,4) d(3,4,11)		

5. Discussion and Conclusions

The risk management of defect repairs for existing apartments is focused primarily on individual management methods such as the improvement of construction methods. As a result, it is difficult to identify the cause of defects resulting from complex mechanisms; hence, there is a limit in deriving the fundamental reduction measures. This study identified the problems of individual risk assessment methods and proposed a risk quantification technique that introduced the LDA (loss distribution approach). The main objective of this study is to construct a classification system based on the defect type, work type, and defect location, by applying the proposed evaluation method. Afterwards, the defect risk profile was systematically analyzed according to the defect liability period by simultaneously considering the frequency and cost. Using methods that have already been proven in the financial field is useful for analysis from a variety of perspectives.

The results of the analysis for the defect risk profile by the DLP in this study are described below. First, in the case of two years of DLP, the severity of the incorrect installation defect and the frequencies of the missing task and detachment were relatively high in the finish work. The analysis results revealed that the loss of defect types that require reconstruction, such as incorrect installations and missing tasks, is high overall in the all shared/exclusive areas. These defects are characterized by easy visual verification.

Second, in the case of 3 years of DLP, the loss of crack defects on the outer wall of RC was relatively high. It was found that cracks and damage defects occurred in the concrete due to the influence of external factors on the parts exposed to the outside. Furthermore, the MEP work had relatively high losses of missing tasks, which affected the functionality defects. The insulation work showed relatively high losses due to the incorrect installations and the excess moisture defects. The corresponding function was affected because the process of the corresponding defect did not work well with other various processes.

Third, in the case of 5 years of DLP, the defect losses of the RC work and waterproof work were relatively high. The RC work had a high defect frequency in the waterproof work. In particular, defects such as cracks in the structure of the underground parking lot along with poor waterproofing work, required reconstruction. These defects have a relatively high risk according to the influence of the groundwater.

Fourth, in the case of 10 years of DLP, high losses were caused by various types of defects such as cracks, surface appearance, water leakage, detachments, and corrosion of the RC work in all of the general public areas. The cracks of the RC work generated in the previous period have relatively high defect risks because they are accompanied by secondary defects such as surface appearance and water leakage.

This study proposes a defect risk management strategy reflecting the characteristics of defect risks analyzed above. In other words, based on the risk profile for each period, the major defects to be considered in the design, construction, handover, post-handover, and occupancy phases, and defect risk management strategies for each defect were derived.

The defect risk matrix proposed in this study has four dimensions: defect type, location, work type, and service life period. However, the defect risk matrix can be analyzed in more detail by adding the dimensions of the components. Another option is performing a multi-faceted analysis through item linkage and integration. If the defect risk matrix is further subdivided and sufficient data is available to produce meaningful results, it is possible to derive effective ways to manage the risk of the defect.

If the practical applications of the LDA in this study are expanded, this will effectively contribute to minimizing unnecessary losses caused by defects by quantifying the defect risks by the period. In other words, the average value of the probabilistically derived total distribution of losses can be calculated based on the amount of losses due to the defects. Then, the level of the defect cost can be identified using percentiles from the perspective of each party to the defect dispute, which includes construction companies and consumers. Consequently, it is expected to be useful for coordinating in the dispute reconciliation process. This loss distribution can be derived for each cell to enable multifaceted analysis, thus assisting in flexible decision making.

The LDA-based defect risk analysis method proposed in this study is a post evaluation method. However, to minimize the defect risks, it also needs measures to minimize the defects identified in this study in advance. In reality, defects occur due to various causes before the construction process. For example, a more detailed analysis is required to identify the obvious causes of cracks in concrete structures that are inevitably created. In this context, it necessary to analyze the mechanism of defects that has not been identified through defect package pattern analysis for the construction project lifecycle and to explore quality control measures that can prevent the defects in advance.

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