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Causes of Defects in Buildings and their Relationship with Life Cycle - Design, Construction and Post Occupancy Stage

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Abstract

Defects have always been a matter of concern for stakeholders in construction industry, as they lead to additional running cost of project during the post occupancy stage. It is essential to identify the causes of these defects so that rectification measures can be expedited. For the purpose of research, the building life cycle is classified into three stages; design, construction and post occupancy. An investigation into the causes of defects is carried out through structured questionnaire survey based on Guttman's scale, from architects working in Indian construction industry. Twelve causes of defects related to different stages of building were examined. The descriptive data analysis and cross-tabulation of data resulted in some interesting facts. The research concluded that major causes of defects in buildings are associated with construction and post occupancy stage of building, and can be listed as; dampness/seepage in buildings, poor workmanship, lack of quality control, improper installation of services and lack of maintenance.

1.Introduction

Defects in building have an impact on the life cycle cost, as they are liable for huge investment, before the useful life of building is over. In context of a building contract, defect is defined as failure of the accomplished project to fulfil the quantity obligation and the implied quality (Cama, 2004). The life cycle of a building is comprised of four major stages; design, construction, post occupancy or maintenance, and demolition stage. The defects occurring in a building have direct relationship with the quality of work and it must be related to cost to achieve the total quality management system (Abdelsalam and Gad, 2009). Hasan et al. (2016) argued that improved workmanship, identified responsibility for all parties, frequent meetings for evaluating progress, selection of good quality building materials, usage of modern construction methods, readable drawings, compliance with specifications, regular and proper inspection on site, are most effective strategies for minimising defects in building construction projects. Incorrect methods of construction, selection of poor materials and bad labour practices lead to design and construction defects (Olanrewaju et al. 2010). Besides this, the maintenance management during post-occupancy stage also contributes towards the life cycle cost of building. It is presumed that the likely causes of these defects have their roots underlying in different stages of a building, i.e., design, construction and post occupancy stage. The endeavour of this research is to investigate these causes of defects and establish their relationship with the different stages of building. The opinion of architects in India, are collected for data analysis.

2. Literature Review

Defects can be divided into two categories; based on their occurrence time and nature of defect. The defects are sometimes referred as patent and latent defects, which are related to their time of occurrence. Latent defects are hidden defects caused by the designers that become apparent at some later date, whereas patent defects are caused by the constructer (Cama, 2004). Patent defects are can be discovered upon examination or in other words, these are shortcoming in a structure that are apparent to reasonable inspection (Chan, 2002). The nature of defects can be classified as structural and non-structural, depending upon the severity of damage caused or likely to occur in future. The defects have an impact on the life cycle cost, that is defined as, the current value of an asset over its operating life that includes; the initial investment cost, cost of occupation, operating costs, and also the profit earned after disposal of the asset when the useful life is over. Broadly speaking, the life cycle costs can be classified as; Capital costs, Costs-in-use, and finally the costs involved in disposal of the property. The capital cost includes cost of construction including all services. The maintenance costs are a component of cost-in-use, considering all recurring costs. The running, repairs and replacement required will cover costs-in-use, and it is accepted that all of these are subject to be considered well during the design process (Chanter, B. and Swallow, P., 2007). The activities performed during three stages; design, construction and post-occupancy, need to be examined in order to further investigate on their relationship with the defects and their causes.

Bakri and Mydin (2014) have summed up structural defects as: Cracks in walls caused by overload or because the structure has settled or heaved; Unstable Foundation because of movement of the soil, faulty design, overload (Dead and Living Load), material strength, or natural Disaster. Borku, W.T. (2020) state that structural defects in roof, stairs, cracking door and window are caused likely because of poor quality of construction materials, poor workmanship, lack of site supervision, poor construction practices or mix design problems. Bakri and Mydin (2014) have also identified non-structural cracks in buildings, such as: Peeling paints (interiors) due to poor surface preparation; Peeling paints (exteriors) surfaces due to exposure to the rain, sun, thermal variation, and new plastered or skimmed walls or ceiling are not given enough time to completely dry before painting; Dampness due to rain,

condensation, flooding, service leaks, construction process, or improper usage of building; Non-biological deterioration in timber because timber in service being subjected to environmental exposure, living organisms such as insect infestation, fugal decay and marine borers, design alterations, poor maintenance, wood boring insects, fungal decay; Mold and fungi due to water damage, high humidity, or dampness; Cracks due penetration of rain to the external surface of structural; Manmade holes; Plaster falling off from ceiling because of vibration due to usage; Shrinkage Cracking due to usage of strong mixes of render on weak or bad prepared background; defects of Rendering (exterior plaster) due to loss of bond between coats, surface cracking, friable powdery surfaces, water damage from overflowing tub, leakage in the toilet or shower, seep out of plumbing or roof, storm damage, cracks around a chimney or movement of structure. Borku, W.T. (2020) also stated some non-structural defects such as: Honeycomb, Peeling of paint, Dampness penetration, Vegetable growth on buildings due to poor maintenance, poor project management, poor quality of construction materials, poor workmanship, lack of site supervision, and poor construction practices. Lack of coordination of design work, errors in production planning, erroneous craftsmanship, and late deliveries are common defects (Josephson and Hammarlund, 1999).

Natural hazards are unpredictable and so are the defects related to them. These hazards may cause damage ranging from minor cracks to collapse of the structure. The codes provide some provision to design buildings taking safety measures, so that collapse can be prevented. However, the probability of defects occurring due to natural hazards including movement of soil beneath the building due to earthquakes cannot be ignored. Gryna (1988) defines cause as a demonstrated basis for the occurrence of a defect. Hence, it is essential to focus on causes of defects during different stages of building project.

2.1. Defects and the Design stage

The design stage has the greatest scope for technical performance problems to originate. It is assumed that poor detailed design practices can contribute towards performance problems during the later life of a building. In other words, the real cause exists during an earlier stage. The defects occurring during the later life of a building may be easily associated with the detailed design stage. The introduction of high technology in building construction demands greater emphasis on the need to co-ordinate design from both perspectives, i.e.; technical and organisational. There is a need for better co-ordination i.e., design management practices, and checking systems (Chanter, B. and Swallow, P.,2007). Hasan et al. (2016) highlighted causes such as poor design, low-quality workmanship, construction not according to design, or exposure of the building to variables not accounted for in the design, as liable for defects in construction project. The study also considered the impact of the design's buildability on the quality of work and the long-term durability of building materials.

2.2. Defects and the Construction stage

Defects can occur in a building during construction stage, defects liability period, and post defects liability period also. It has been verified that most defects occurred during construction stage (Ede, 2010). A study was conducted by Chong and Low (2005) to investigate defects at construction stage of building, and it was observed that internal wall defects accounted for 89% of all defects, with workmanship problems as the cause of defect. As per the building feature and stage of occurrence, the following causes were investigated: the frequency of design, workmanship, material, lack of safety, and maintenance. Chanter, B. and Swallow, P. (2007) emphasized that execution on site is an important stage and site supervision, checking of materials on site, and workmanship must be focussed on. However, employing building materials of low quality is identified as main cause of building collapse (Oloyede et al., 2010) and high maintenance (Hashim et al, 2015). Isa et al. (2016) researched for the causes of architectural defects in Malaysian university house and identified most common causes as; work did not meet specifications, poor workmanship, lack of safety, vandalism, and water seepage. According to Kim et al. (2019) defects are mostly caused by human or process errors and there are a few causes of defects in residential buildings, such as; lack of control, accelerated schedules, construction by inexperienced staff, material defects, and insufficient inspection.

2.3. Defects and the Post occupancy stage

Chanter, B. and Swallow, P. (2007) emphasised that a considerable number of construction failures are contributed due to poor maintenance practices, like; inadequacy of routine maintenance, non-implementation of an ineffective replacement planning, lack of regular and proper inspections, non-availability of data to enable the maintenance so that it can be properly carried during the post occupancy period. The buildings may last for centuries, if they are properly maintained. It is also of crucial significance that the maintenance managers are involved at the design stage.

Chong and Low (2005) found that at the occupancy level, mechanical and electrical components accounted for 73 % of defects caused by design flaws. Incorrect installation affects construction project efficiency and workmanship, design, management, equipment, material, or lack of safety of already installed objects are the most common sources of defects traced in construction projects. These defects can be associated with adjustments, mistakes, omissions, or harm (Alencastro et al., 2018).

2.4 Cost of defects

According to Ali et al. (2010), the building maintenance efforts in the United Kingdom have surpassed 50% of all annual construction operations. According to studies, 70-85 percent of building maintenance and running costs can be controlled during the design stage. It accounts for a significant amount of total building life cycle costs, and there has been a recent rise in awareness of the need of budgeting for building maintenance and operations (Krstic and Marenjak,2012). Josephson and Hammarlund (1999) stated that the defect costs account for 4.4 percent of total manufacturing costs. The time it takes to correct them is about 7% of the overall time spent on the job. Rework of defective components discovered late during construction wastes 6-15 percent of construction costs, while rework of defective components detected during maintenance wastes 5% of construction costs (Akinci and Boukamp, 2004).

3. Research Methodology

The literature review highlighted issues related to likely causes of defects during life cycle of building. These causes can be summarised as; natural hazards, movement of soil beneath the building, dampness/seepage in building, inadequate drainage system, faulty design, poor workmanship, faulty plumbing, lack of quality control on building material, non-adaptability of building for future demands, improper installation of building services (during construction and post occupancy), alterations during post occupancy, lack of maintenance.

3.1 Research questions

The research aimed to investigate the causes of defects those are related to different stages of building life cycle i. e., Design, Construction and post occupancy. Further, it also aims to explore whether the professional experience, in terms of number of years and exposure of respondents changes their opinion towards the causes of defects. An attempt was made to enlist the possible causes of defects through literature survey and conduct a questionnaire survey to analyse the research questions.

3.2 Instrument design and data collection

In order to investigate the causes of defects in buildings during life cycle of buildings, an online structured close-ended questionnaire was designed and the survey was conducted through a non-probability sampling method. The questionnaire consisted of two parts. Part A comprised of questions related to the profile of respondents and included a set of closed-ended questions with a single choice. Part B comprised of twelve causes of defects. Attitude

scaling was adopted based on Guttman's scale that helps to measure the composite scores (Dixit, 2011). The target group were 200 architects with variation of professional backgrounds, such as: academicians, practitioners, and both. Akintoye (2000) have stated that receiving 20-30% response is acceptable in the construction industry and the response rate for the survey conducted as 62%, that can be assumed to be acceptable.

4. Data Analysis

The demographic profile concerned the profession category, experience, and budget of the projects handled by respondents. The highest response rate was from practicing architects (64.7%) and from architects having experience of 0-20 years (87.9%). Majority of architects (62.9%) had an experience of handling projects of budget above 5 Crores. The descriptive analysis conducted for 'Part A' was based on three indicators of architect's profile as illustrated in Table 1.

Table 1. Demographic profile of respondents

Profile	Category	Frequency (n)	%
Professional Experience/ Job position	Academicians	11	9.5
	Practicing architects	75	64.7
	Both	30	25.9
Working experience	0-10	66	56.9
	11-20	36	31.0
	21-30	8	6.9
	31-40	3	2.6
	Above 40	3	2.6
Budget of projects	30-50L	10	8.6
	51L-1.5Cr	7	6.0
	1.6-2.5Cr	9	7.8
	2.6-5.0Cr	10	8.6
	Above 5.0Cr	73	62.9
	Not applicable (for academicians)	7	6.0

% - percentage, n- sample response, L-Lakh, Cr-Crores

The general perception of respondents regarding the causes of defects is demonstrated in Figure 1.

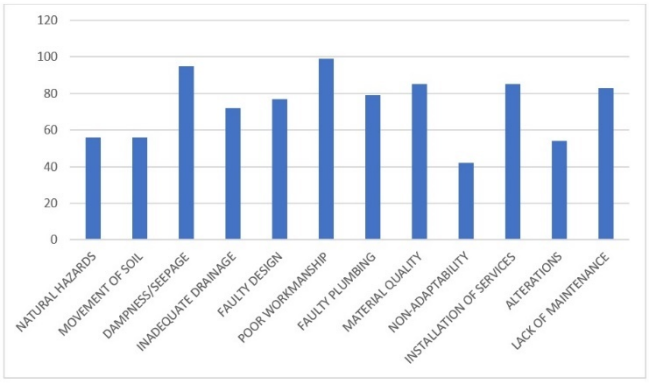

Figure 1. General perception for causes of defects

It is observed that highest response is received for poor workmanship (86.1%), dampness and seepage in buildings (82.6), lack of quality control and improper installation of building services (both at 73.9%), and lack of maintenance (72.2%). Lowest response is in favor of non-adaptability of buildings for future demands (36.5%).
A descriptive analysis of the data was also performed to obtain frequencies and cross-tabulation of data was conducted on the basis of their experience, profession and budget of projects handled, as presented in Figure 2, 3, and 4 respectively.

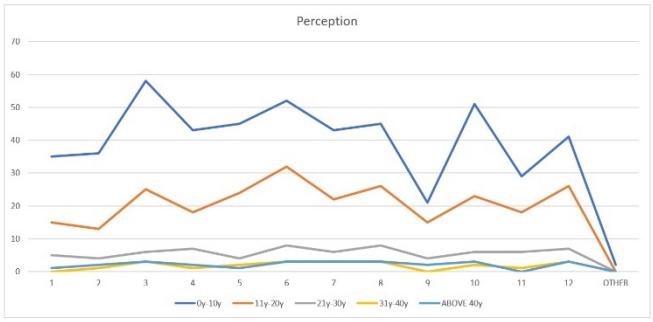

Figure 2. Cross tabulation of experience of respondents with causes of defects

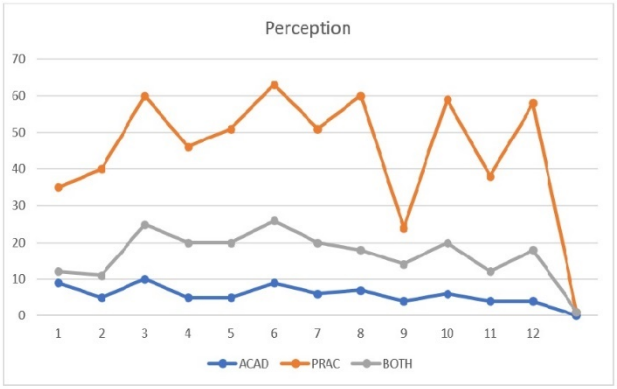

Figure 3. Cross tabulation of type of profession with causes of defects

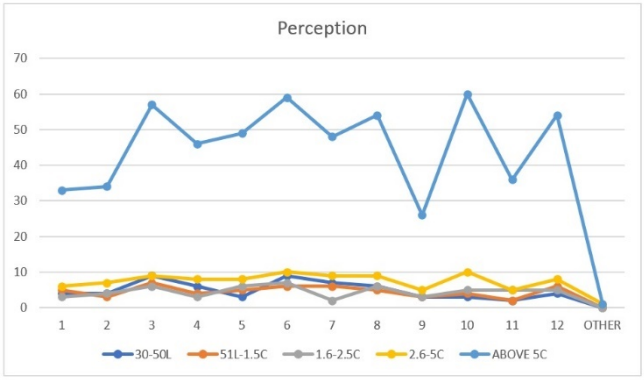

Figure 4. Cross tabulation of budget of building with causes of defects

On close examination, it is observed that the profile of responses for various causes of defects is similar when cross-tabulated with years of experience and profession. On the contrary, the response received from projects above 5 crores of budget are distinguishably different from all other projects of lower budget. A comparative description of frequencies for responses obtained after cross-tabulation is presented in Table 2, that includes data that is related to distinguishable frequencies only.

Table 2. Comparable frequencies for causes of defects

CAUSES	BUDGET (Above 5 Cr) n	Exp 0-10y n	Exp 11-20y n	Profession Practicing n
Natural hazards	33	35	15	35
Movement of soil	34	36	13	40
Dampness/seepage	57	58	25	60
Inadequate drainage	46	43	18	46
Faulty design	49	45	24	51
Poor workmanship	59	52	32	63

Faulty plumbing	48	43	22	51
Lack of quality control	54	45	26	60
Non adaptability	26	21	15	24
Improper services installation	60	51	23	59
alterations	36	29	18	38
Lack of maintenance	54	41	26	58
Other	1	2	0	1

n – frequency, Cr-Crores, y-years

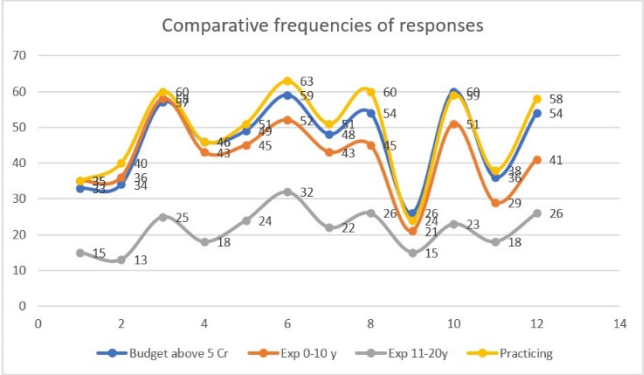

Figure 5. Comparative frequencies for causes of defects

It can be verified from Figure 5, that the most commonly recognised causes of defects in buildings identified by three categories of respondents; practicing, having 11-20 years of experience, and those who have handled projects above 5.0 Cr, are dampness/seepage in buildings, poor workmanship, lack of quality control, improper installation of services and lack of maintenance.

Further, an investigation was carried out to examine the significance of the relationship between the opinion of architect's having different professional background. A scatter diagram was plotted between the academician's response and practising architects' responses as shown in Figure 6. Scatter plot is a method of regression analysis or line of best fit (Oberoi, 2012). The scatter plot confirms the positive association between two categorical variables (Figure 6) i.e., similarity in responses towards the causes of defects in this case.

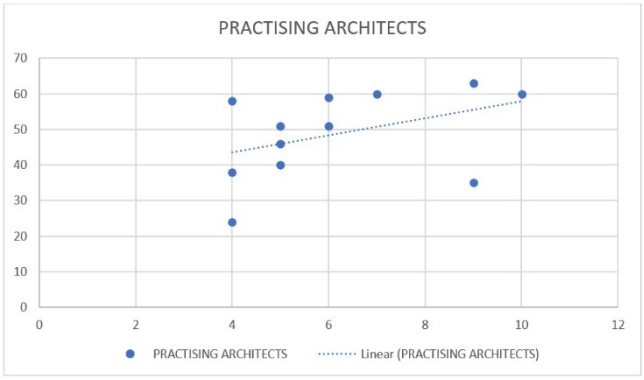

Figure 6. Scatter plot showing positive association between opinion of academicians and practicing architects

5. Conclusion

Exhaustive literature review was done to identify the causes of defects and they were further investigated through questionnaire survey to identify the most common causes. The three stages during life cycle of building were identified as; Design, construction and post occupancy. Further discussion is mandatory to classify these causes of defects in different stages of building life cycle. The causes of defects associated with the Design stage are; Inadequate design of drainage system (62.6%), faulty design (67%), non-adaptability of building for future demands (36.5%), and movement of soil beneath the building (48.7%). Movement of soil can be due to non-consideration of soil type during structural design exercise. The causes of defects related to construction stage are; poor workmanship (86.1%), faulty plumbing (68.7%), lack of quality control on building material (73.9), and improper installation of building services (73.9%). The causes of defects associated with post-occupancy stage are; dampness/seepage in building (82.6%), alterations (47%), and lack of maintenance (72.2%). Some causes such as natural hazards (48.7%) are unpredictable.

The opinion of respondents having professional experience in architecture of upto 20 years illustrates that the issues related to construction and post occupancy stage such as; dampness/seepage in buildings, poor workmanship, lack of quality control, improper installation of services and lack of maintenance, are critically responsible for defects in buildings. These responses are in coordination with the academician's opinion also (reference to Figure 6). It is also observed that non-adaptability of building for future demands, movement of soil beneath the building, alterations during post occupancy are not majorly responsible for defects in buildings.

6. Limitations of study and future scope

The research is conducted in Indian construction industry and is limited to the opinion of architects only. The opinion of other stakeholders from construction industry may vary from these results and prove some contradiction. Further analytical studies can be conducted to examine the understanding of different stakeholders and in different context of places.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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