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HAMMA-ADAMA, M., IHEUKWUMERE, O. and KOUIDER, T.

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Analysis of Causes of Building Collapse: System Thinking Approach

Mansur Hamma-adama [1)]***, Obinna Iheukwumere*** [2)] ***and Tahar Kouider*** [3)]

[1)] Robert Gordon University Aberdeen, United Kingdom. E-Mail: m.hamma-adama@rgu.ac.uk
[2)] Robert Gordon University Aberdeen, United Kingdom. E-Mail: o.e.iheukwumere@rgu.ac.uk
[3)] Robert Gordon University Aberdeen, United Kingdom.

ABSTRACT

Construction industry has rapidly evolved in the past decade. Across some developing nations, the issue of building collapse has remained a disturbing factor, especially in the past three decades. In Nigeria, building collapse has become the subject of much academic discourse, albeit without many tangible improvements. For instance, after every incidence of building collapse in Nigeria, investigations are usually carried out and actions are taken. Unfortunately, the menace appears to have exacerbated in recent times. This study investigates the causes of building collapse in Nigeria from academic literature with a view of identifying the leading causes which may shape future government policies while seeking to address the situation. A system-thinking approach was adopted to build a causal loop diagram showing the interrelationships among all the identified factors. With the aid of a system-thinking software, Vensim, a causal loop model was developed which helped identify key leverage points on which policies can be based to control excessive building collapse in Nigeria. Three leverage points were identified as differential settlement, structural failure and structural issues, which are linked to the civil engineering discipline. Recommendations are made based on the study findings.

KEYWORDS: Building, Causes, Collapse, System thinking.

INTRODUCTION

Building construction is as old as humans' existence. Materials and processes of building construction have been progressively changing from pit-house development and grass shelters to more permanent structure (Niroumand et al., 2013). Permanently built structures are also evolving and advancing from a horizontal development to a vertical one. Building construction comes with loss of materials, health and lives predominantly in developing countries. These losses begin from the on-site construction health and safety perspectives (Islam et al., 2017; Al-Khaburi and Amoudi, 2018) to the post-construction stage. In a further development, vertical development of building brings advantages in space utilization, conservation of plant spaces, … etc. These advantages also come with a price for many developing countries like Nigeria. Multi-storey building collapse has been a single challenge in the Nigerian construction industry that lasted decades and its impact is considerably high (Hamma-adama and Kouider, 2017). Between 1971 and 2016, over 170 buildings were reported to have collapsed in Nigeria and about 1500 lives were lost (Omenihu et al., 2017). Investigations upon investigations were carried out and workshops and conferences were held to bring this menace to an end. However, that has not seemed to have laid the issue down, as more buildings are collapsing every year. Despite the availability of the identified causes of building collapse in the academic, professional and public domains, there is still reported building collapse in several locations of the country. There was an attempt by Ayodeji (2011) to generate a relationship between the number of collapsed buildings and causes of the collapse. It was then established that poor materials and workmanship were the dominant (55%) causes of building collapse in Nigeria. However, what is the relationship between the remaining causes with poor materials and workmanship? Moreover, what is the relationship between other secondary causes along the process of failure and subsequent collapse of buildings?

This study attempts to correlate the various causes of building collapse, establish their relationships and

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explore relevant perceptions and possibilities. The study intends to be achieved through a literature review to generate data and analyze the data using a system thinking approach. The data represents the causes of building collapse, their scale of importance and impact from previous studies. Using system thinking approach, relationships of these causes are established to make an informed decision to stop the continuous building collapse in Nigeria.

LITERATURE REVIEW

Building Construction and Its Challenges

Construction industry in Nigeria has been operating in a chaotic manner due to lack or inadequate legislative provisions regarding building codes. The current national building code (2006) appeared to be ineffective as a result of weak enforcement and corruption within the regulating agencies, especially when it comes to building development approvals (Oyedele, 2018). This situation is a significant contributor to most of building collapse causes (i.e., monitoring, deception, change of building usage/excessive loading, … etc.).

Building collapse is a major issue and a continuing challenge of building construction in Nigeria. Private and public buildings account for more than 90% of the reported building collapse cases between 1980 and 2010 (Fagbenle and Oluwunmi, 2010), 60% of which could not secure approval of the development before construction commenced. On the other hand, the Federal Capital Territory (FCT) is reported to have had less building collapses in the country (Omenihu et al., 2016, Table 1), despite being the most expanding city in the country.

A study on one hundred and five (105) collapsed buildings between 1978 and 2007 revealed that structural defects are attributed to 69% of the collapses, while 16% were due to poor materials (Oni, 2010). However, another study attempted to generate a relationship between the number of collapsed buildings and causes of the collapse (between 1981 and 2005). It was a bit of leap to conclude that poor building materials and workmanship were the highest (55%) contributors to collapse of buildings in Nigeria (Ayodeji, 2011). Ayodejis' study (2011) can be considered as a sub-set of Oni's research (Oni, 2010) due to the range of years and the number of collapsed buildings found in both studies. Thus, structural defects are most likely to be considered dominant. On the other hand, structural defects represent a secondary cause of building collapse, meaning that it comes as a result of a primary cause. The primary cause may lie in poor building material(s), faulty design, lack of supervision, … etc. Structural defects could be the last observed cause before a building gives way (collapses). Still, the fault must have originated somewhere, somehow within the design and construction processes or even during the use of the building itself.

Building collapse in Nigeria brings about many effects under different categories; such as social, economic and environmental problems (Ibrahim et al., 2019). These effects include, but are not limited to, the following:

- Loss of lives (in hundreds) as surveyed and reported by Arayela and Adam (2001).
- Loss of properties and capital investments: resources are damaged beyond re-use. Capital investments are not recoverable, leading to bankruptcy and high economic implications to the economy of the nation (Chendo and Obi, 2015).
- Loss of reputation and integrity resulting in psychological trauma.
- Environmental issues through CO_2 emissions in re-building the collapsed structure and non-biodegradable waste generated from the debris due to lack of recycling culture.

Causes of Building Collapse

Building collapse occurs when the building could not withstand its weight (dead load) and/or the pressure imposed on it (live load). A building mostly collapses when one or more of its critical structural component(s) fail (Michael and Razak, 2013; Khazaee et al., 2017). These critical structural components include; roof, slab, beam, column, foundation (including sub-surface of the foundation) or sometimes even walls (Ejiofor, 2018). There are numerous causes of building collapse in Nigeria and these causes are classified under two groups; human-made causes and natural causes (Okagbue et al., 2018). The human-made causes of building collapse are collapse caused by actions/inactions of man, such as human errors, negligence, quackery, … etc. (Omenihu et al., 2016), while the natural causes are those causes beyond human

intervention, such as flood, earthquake, landslide, mudflow, … etc. Human-made causes of building collapse usually happen during design, construction and use of a building, while natural causes mostly occur within the lifespan of a building, during building occupancy.

The causes of building collapse at design and construction stages are the most dominant (Ibrahim et al., 2019), if not the only causes of building collapse in Nigeria. Although the impact of natural disasters may be considered at the design stage of a building to accommodate such adversities, that is mostly done in disaster-prone zones. Thus, such design factors usually are not considered during building design in Nigeria.

Table 1 presents a summary of dominant causes of building collapse in Nigeria based on the past 20-year studies.

Table 1. Causes of building collapse in Nigeria (compiled by the authors)

S. No.	Causes of building collapse	Sources
1	Sub-standard building materials	Oyedele, 2016; Omenihu et al., 2016; Omenihu et al., 2017; Oni, 2010; Ayedun et al., 2011; Ayodeji, 2011; Ewa, 2018; Fagbenle and Oluwunmi, 2010; Chendo and Obi, 2015; Ibrahim et al., 2019; Omran et al., 2016; Ajufoh et al., 2014; Ede et al., 2016; Taiwo and Afolami, 2011; Olagunju et al., 2013a; Ebehikhalu and Dawam, 2014; Okagbue et al., 2018; Matawal, 2012; Ejiofor, 2018; Michael and Razak, 2013.
2	Bad building base/ foundation failure	Oyedele, 2016; Omenihu et al., 2017; Chendo and Obi, 2015; Ibrahim et al., 2019; Obam et al., 2013; Ebehikhalu and Dawam, 2014; Ejiofor, 2018.
3	Poor workmanship/ faults on the construction site	Oyedele, 2018; Omenihu et al., 2016; Ayedun et al., 2011; Ayodeji, 2011; Omenihu et al., 2017; Oni, 2010; Oyedele, 2016; Fagbenle and Oluwunmi, 2010; Chendo and Obi, 2015; Ibrahim et al., 2019; Hamma-adama and Kouider, 2017; Ajufoh et al., 2014; Okolie et al., 2016; Ede et al., 2016; Olagunju et al., 2013; Ebehikhalu and Dawam, 2014; Michael and Razak, 2013.
4	Faulty design	Oyedele, 2016; Oyedele, 2018; Omenihu et al., 2017; Omenihu et al., 2016; Ayodeji, 2011; Oni, 2010; Ogunbiyi et al., 2015; Chendo and Obi, 2015; Ibrahim et al., 2019; Ajufoh et al., 2014; Olagunju et al., 2013b; Ebehikhalu and Dawam, 2014; Matawal, 2012; Ejiofor, 2018; Michael and Razak, 2013; Taiwo and Afolami, 2011; Ewa, 2018; Fagbenle and Oluwunmi, 2010; Okolie et al., 2016.
5	Structural failure/defect	Omenihu et al., 2016; Hamma-adama and Kouider, 2017; Ayedun et al., 2011; Oni, 2010; Ogunbiyi et al., 2015; Oyedele, 2016; Fagbenle and Oluwunmi, 2010; Ajufoh et al., 2014; Ebehikhalu and Dawam, 2014; Okagbue et al., 2018; Michael and Razak, 2013.
6	Quackery	Omenihu et al., 2017; Omenihu et al., 2016; Adetunji et al., 2018; Ewa, 2018; Fagbenle and Oluwunmi, 2010; Chendo and Obi, 2015; Ibrahim et al., 2019; Omran et al., 2016; Ajufoh et al., 2014; Ebehikhalu and Dawam, 2014; Ejiofor, 2018.
7	Illegal conversion/ alterations/ additions to existing structures (excessive loading)	Omenihu et al., 2017; Adetunji et al., 2018; Ewa, 2018; Fagbenle and Oluwunmi, 2010; Chendo and Obi, 2015; Ibrahim et al., 2019; Omran et al., 2016; Ajufoh et al., 2014; Ebehikhalu and Dawam, 2014; Ejiofor, 2018; Michael and Razak, 2013; Ayedun et al., 2011; Ayodeji, 2011; Taiwo and Afolami, 2011.
8	Inadequate or lack of supervision	Omenihu et al., 2017; Adetunji et al., 2018; Fagbenle and Oluwunmi, 2010; Ibrahim et al., 2019; Omran et al., 2016; Ebehikhalu and Dawam, 2014; Ejiofor, 2018; Michael and Razak, 2013; Ayedun et al., 2011; Taiwo and Afolami, 2011; Hamma-adama and Kouider, 2017; Ede et al., 2016; Okagbue et al., 2018; Matawal, 2012.
9	Dilapidating structure (poor maintenance culture)	Ayedun et al., 2011; Ayodeji, 2011; Omenihu et al., 2017; Oni, 2010; Olagunju et al., 2013; Ebehikhalu and Dawam, 2014.
10	Geotechnical issues	Omenihu et al., 2017; Oyedele, 2016; Chendo and Obi, 2015; Obam and Nwaogu, 2017; Ede et al., 2016; Taiwo and Afolami, 2011; Matawal, 2012; Ejiofor, 2018.
11	Demolition process	Omenihu et al., 2017; Ebehikhalu and Dawam, 2014.
12	Fire incidence	Oni, 2010; Chendo and Obi, 2015; Olagunju et al., 2013.
13	Non-consultation of professionals	Ajufoh et al., 2014; Ebehikhalu and Dawam, 2014; Adetunji et al., 2018.
14	Corruption	Chendo and Obi, 2015; Ibrahim et al., 2019; Omran et al., 2016; Okolie et al., 2016; Ede et al., 2016; Taiwo and Afolami, 2011; Okagbue et al., 2018.
15	Failure of the client to pay professional services	Omran et al., 2016.
16	Monitoring/ enforcement	Onwuanyi, 2016; Ebehikhalu and Dawam, 2014; Hamma-adama and Kouider, 2017.

Sequel to the compilation of building collapse causes in Nigeria, there are some attributes or variables of importance to understanding the failed component(s) and stakeholder responsible for these components. Table 2 presents the generated variables of collapse causes.

Table 2. Variables of building collapse causes (generated by the authors)

S. No.	Causes of building collapse	Classification of the causes	Failed element or component(s)	Area of specialty/ Stakeholder(s) responsible
1	Sub-standard building materials	Primary	Structural components	Structural Engineering/ Structural Engineer
2	Bad building base/ foundation failure	Secondary	Structural components	Structural Engineering/ Structural Engineer
3	Poor workmanship/ faults on the construction site	Primary	All building components	Architect/ Project manager and Engineers
4	Faulty design	Primary	All building components	Architect and Engineers
5	Structural failure/defect	Secondary	Structural components	Structural Engineering/ Structural Engineer
6	Quackery	Primary	All building components	Architect and Engineers
7	Illegal conversion/ alterations/ additions to existing structures (excessive loading)	Primary	All building components	Owner, Architect and Engineers
8	Inadequate or lack of supervision	Primary	All building components	Owner, Architect and Engineers
9	Dilapidating structure (poor maintenance culture)	Secondary	All building components	Owner/Client
10	Geotechnical issues	Primary	Foundation	Structural/Geotech. Engineer
11	Uncontrolled demolition	Secondary	All building components	Owner/ Client
12	Fire incidence	Secondary	All building components	Facility Management/ Manager and Structural Engineer
13	Non-consultation of professionals	Primary	All building components	Owner/ Client
14	Corruption	Secondary	All building components	Client and Professionals
15	Failure of the client to pay professional services	Secondary	All building components	Owner/ Client
16	Monitoring/enforcement	Primary	All building components	Government Agencies

METHOD OF STUDY

This study aims to review the literature on building collapse, specifically its causes in Nigeria, and determine the relationships between these causes. Systematic mapping was adopted in providing a base for the study. This is to determine whether there is evidence for the study and its magnitude (Kitchenham and Charters, 2007). Going by the study definition, identifying the subject/topic of interest or research questions, a systematic mapping was followed as in (Petersen et al., 2008). Thus, a systematic literature review guideline by Kitchenham and Charters (2007) was used. At the beginning of this study, ScienceDirect was considered as the database for the literature search; however, the database did not yield substantial

publications within the study context (Nigeria). As a result, a Google scholar was used as a search engine, where publications within around databases are reached. Sixty-six publications (journals and conference papers) initially appeared from the search carried out using combinations of the following keywords: "building collapse", "causes of building collapse" and "causes of building collapse in Nigeria". The search was based on published papers within the last 20 years (2000-2019). A scoping review was conducted on building collapse research and a systematic approach was adopted in selecting the relevant studies developing or assessing causes of building collapse in the study context (Paré et al., 2015). The developed papers on building collapse in Nigeria were firstly selected based on title and context; then subsequently reduced through content in their abstracts. These papers are used for review and development of the causes of building collapse (as data) was used in the study. Figure 1 presents a systematic mapping of the papers used in generating the study data.

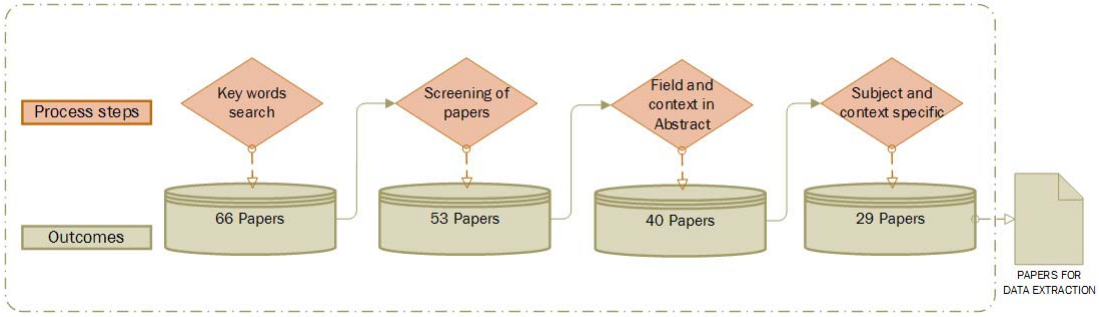

Figure (1): Systematic mapping process (adopted from Petersen et al., 2008)

Due to the systematic mapping process, 29 publications were used in generating causes of building failure in Nigeria and their attributes for subsequent data analysis.

The analysis of data was undertaken using a system-thinking approach. System thinking involves a holistic approach to problem analysis that focuses on the interrelationships of constituent parts of the problem and how they combine to influence its overall behaviour. It is opposed to linear thinking and promotes the understanding of the underlying drivers and dynamics of complex issues. System thinking has been applied across numerous fields, including engineering, physical sciences, business management and even policy studies. Fordyce (1988) applied it to develop an interdisciplinary model for engineering education, while Kapsali (2010) demonstrates its usefulness in improving the success of innovation projects through flexible planning and management of complexity and uncertainty. Monat and Gannon (2015) adopted it for policy studies in predicting and analyzing the behaviour of ISIS.

System thinking utilizes causal loop diagrams (CLDs) as a powerful tool to provide insight into the interrelationships amongst system components and their overall behaviour (Goodman, 1997; Richmond, 2004). It highlights the concept of feedback and time delays between actions and their resultant effects. Two forms of loops come into play in system thinking, a positive reinforcing loop and a negative stabilizing loop. Figure 2 provides an overview of this concept.

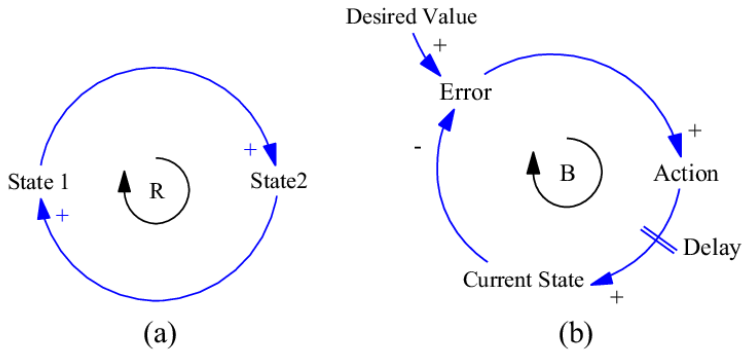

Figure (2): Balancing and reinforcing loops (Source: Lu et al., 2016)

A balancing loop is a loop with an odd number of negative signs. This loop brakes itself (or tends to restore a balance) from a continuously increasing property. An example is the regulation of room temperature by a knob. A reinforcing loop, on the other hand, is a steadily growing phenomenon. It can be exemplified by a certain amount of money fixed in a bank, which continues to yield interest and grow as determined by a favourable interest rate.

DISCUSSION

In the context of building collapse, there are several factors (causes) that contribute systemically to drive this issue. The relationships between these causes as identified in Table 3 were generated through a series of human actions and the resultant vulnerable effects on structural components which compromise building stability and consequently lead to collapses. It is agreed by Fakere et al. (2012) that the failure of structural elements leads to building collapse.

Table 3. Causal relationships between causes of building collapse in Nigeria

S./No.	Causes of building collapse	Classification of the causes	The cause leads to A	A leads to B	B leads to C	C leads to D
1	Sub-standard building materials	Primary	Producing weak structural elements	-	Structural failure	Building collapse
2	Bad building base/ foundation failure	Secondary	Differential settlement	-	Structural failure	Building collapse
3	Poor workmanship/ faults on the construction site	Primary	Structural deformation	-	Structural failure	Building collapse
4	Faulty design	Primary	Poor construction	-	Structural failure	Building collapse
5	Structural failure/defect	Secondary	-	-	-	Building collapse
6	Quackery	Primary	Poor design and construction	-	Structural failure	Building collapse
7	Illegal conversion/ alterations/additions to existing structures (excessive loading)	Primary	Structural deformation	-	Structural failure	Building collapse
8	Inadequate or lack of supervision	Primary	Poor construction	Compromising structural integrity	Structural failure	Building collapse
9	Dilapidating structure (poor maintenance culture)	Secondary	Weakening structural elements	-	Structural failure	Building collapse
10	Geotechnical issues	Primary	Unsuitable foundation	Building settlement and foundation failure	Structural failure	Building collapse
11	Uncontrolled demolition	Secondary	Weakening structural elements	-	Structural failure	Building collapse
12	Fire incidence	Secondary	Weakening structural elements	-	Structural failure	Building collapse
13	Non-consultation of professionals	Primary	Poor design and construction	Compromising structural integrity	Structural failure	Building collapse
14	Corruption	Secondary	Lack of compliance with specifications	Compromising structural integrity	Structural failure	Building collapse
15	Failure of the client to pay professional services	Secondary	Poor design and supervision	Compromising structural integrity	Structural failure	Building collapse
16	Monitoring/ enforcement	Primary	Lack of compliance with specifications	Compromising structural integrity	Structural failure	Building collapse

Causal analysis of building collapse in Nigeria using the identified primary and secondary factors as variables was modelled using the Vensim software to link all the causes according to their interrelationships in generating building collapse. Figure 3 illustrates these relationships; some of the names of the causes (factors) in Table 3 have been transformed into suitable noun variables, which is allowed in system thinking.

From the model (Figure 3), a series of loops describing the relationships of how the various factors interconnect to drive building collapse can be seen. Three balancing loops (B1- B3) link supervision, monitoring strategies, compliance to specifications and alterations amongst other interconnecting factors. Also, there are five reinforcing loops (R1 – R5) linking some of the mentioned factors alongside structural issues, structural failure and differential settlements. The overall objective of this diagram is to help policymakers identify high leverage points on which policies can be applied to curtail excessive building collapse in Nigeria. Looking at the Causes Tree diagram in Figure 4, which is generated from the Vensim model, we can see how factors leading to *differential settlement*, *structural failure* and *structural issues* lead to overall building collapse.

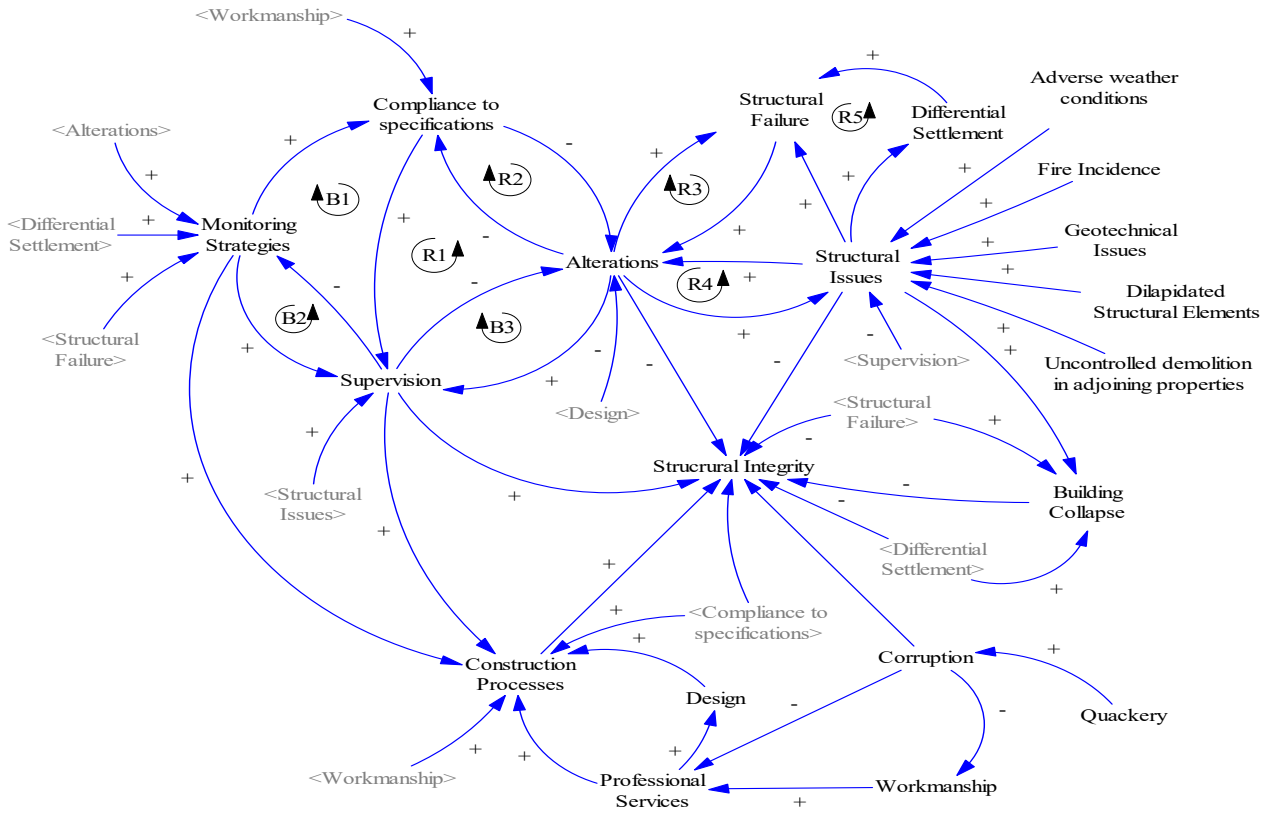

Figure (3): Causal loop diagram for building collapse in Nigeria

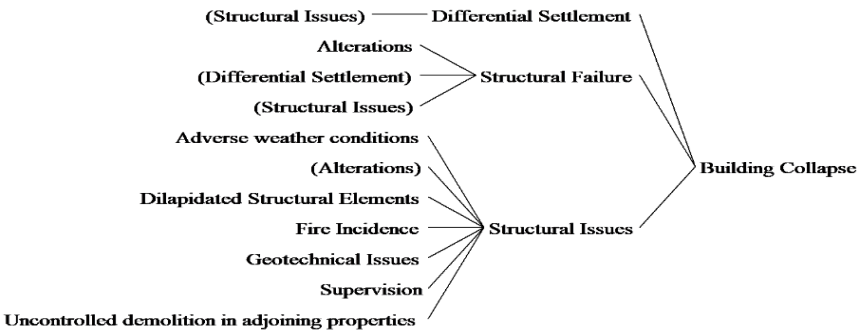

Figure (4): Main factors leading to building collapse in Nigeria

The differential settlement is an issue that causes building collapse; this issue ties to the reliability of the foundation element and to the geotechnical properties of soil. Succinctly, failure originates from the sub-structure of a building and extends its impact to the entire structure. The structural failure is a physical failure mostly observed as a result of a differential or uneven settlement of a building or failure of the structural member(s) caused from within the design or construction perspective. The structural issues are mostly caused by external factors like fire incidence that weakens structural elements, ageing structure, … etc.

It is moreover realized that all the factors are equally important, as they all pose a threat to building collapse. The primary and secondary causes are of the same impact to causing the collapse of building; however, some of the factors need more attention, as they are prevalent and dominant in Nigeria.

CONCLUSIONS

This study adopted a systems-thinking approach to identify the main causes leading to building collapse in Nigeria, using a Vensim model to build a causal loop diagram linking all the identified factors from literature which lead to building collapse in Nigeria. Key leverage points at which policies can be applied to curtail building collapse were identified. These leverage points include differential settlement, structural failure and structural issues. Dealing with the factors that lead to these main causes will certainly help reduce the incidence of building collapse in Nigeria. The study also identified the linked professional stakeholder who is responsible for these leverage points; namely a civil/structural engineer. A policy focused on structural design and its professionalism as well as structural reliability is necessary to achieve a sound structure and stable foundations.

FCT is a clear case study city with very low building collapse despite being the most rapidly developed city in Nigeria. FCT's effectiveness in the area of strict implementation of building approvals, design checks and monitoring of construction supervisions placed it above all big cities with less incidence of building collapse. This study also concluded that all the factors have the same influence to cause the building collapse, but with different prevalence rates in the country.

Recommendations

It is recommended that the quality of building materials in the production of structural elements be the sole responsibility of the structural engineer. Offsite, pre-cast or pre-fabricated structural components should be encouraged to control the quality of structural components. Further study is recommended to examine policy options and approaches to checkmating the structural designs, the process of building approvals and strict supervision of building construction by the certified professionals only.

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