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# A COMPREHENSIVE REVIEW OF FAILURE AND COLLAPSE OF BUILDINGS/STRUCTURES

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## ABSTRACT

*In this paper, the studies of research works related to Failure and Collapse of Buildings/Structures are reviewed. A model which researchers can use for selecting the journal for publishing their research work is proposed.*

**Key words:** Failure, Collapse and Buildings/Structures.

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## 1. INTRODUCTION

The failure and collapse of buildings or structures is a global phenomenon and in most cases result in loss of human lives and civil engineering infrastructures. A number of building collapses were reported, for example Ronan Point apartments collapse in UK when kitchen gas exploded on the 18th floor sending a 25-storey building to the ground in 1968, the 2000 Commonwealth Avenue Tower collapse in Boston in 1971, the collapse of Murrah Federal Building in Oklahoma City in 1995, where air blast pressure caused the collapse of few lower floors while the upper floors failed by progressive collapse. On 29 March, 2008 in Luanda, Angola, a six-storey police building collapsed with detainees. In year 2000, a four-storey commercial building at 14th and 2nd Avenue in Brooklyn, USA, collapsed and vacant building at 124th Street in the north of Manhattan in New York, USA partially collapsed in 2007. In May 2008, a wall collapsed at a building site in Farooq Nagar, the suburb of New Delhi, India. In February 26, 2010, a five-storey residential building under construction

collapsed at Nkolndongo, the suburb of Yaoundé, Cameroon where 4 deaths were reported (Tchamba and Bikoko, 2016) and in 2006, a church collapsed upon the congregation during a service at Kalerwe, a Kampala city suburb, Uganda (Alinaitwe and Ekolu, 2014).

A large body of literature is available on failure and collapse of buildings/structures (Tchamba and Bikoko, 2016; Alinaitwe and Ekolu, 2014; Oloyede et al., 2010; Windapo and Rotimi, 2012). However, there is no paper that proposes a model which researchers can use for selecting the journal for publishing their research works. This paper presents a comprehensive review of failure and collapse of buildings/structures on one hand, and on the other hand it proposed a model which researchers can use for selecting the journal for publishing their research works.

## 2. LITERATURE REVIEW

Geis et al. (2012) studied 1,029 snow-induced building failure incidents in the United States between 1989 and 2009 and 91 international incidents between 1979 and 2009 in 16 countries spanning four continents, as shown in Table 1. The study involved collection of data via newspaper archives, including 1,345 articles from 883 unique sources. They have reported that the most commonly causes of snow-related building failures were excessive snow (89% of total incidents), rain-on-snow (13% of total incidents), and building problems (9.0% of incidents). Structural members experience deterioration as building age elapse and may become damaged. A higher percentage of incidents in older buildings were attributed to building problems, including 28% of historic building incidents and 26% of midage building incidents, compared to 5.4% of new building incidents in the U.S. dataset (Geis et al., 2012). Failures due to melting snow, drifting snow, drainage issues, and people on the roof were also reported.

**Table 1** Distribution of International Database Incidents by Continent and Country (Geis et al., 2012)

Europe		North America <sup>a</sup>		Asia	
Austria	3	Alberta, Canada	1	China	3
Belarus	1	British Columbia, Canada	8	Japan	2
Czech Republic	4	Manitoba, Canada	3	Lebanon	1
England	2	Newfoundland, Canada	1	Total	6
France	2	Nova Scotia, Canada	3		
Germany	1	Ontario, Canada	17		
Italy	1	Prince Edward Island, Canada	2		
Norway	3	Quebec, Canada	16	Australia	
Poland	2			New South Wales, Australia	3
Romania	2			South Australia, Australia	1
Russia	8			Victoria, Australia	1
Total	29	Total	51	Total	5

<sup>a</sup>Excluding United States of America.

Danso and Boateng (2013) conducted an experimental investigation to assess whether the quality of Type I Portland cement used in Ghana is a contributor to the recent building collapse in Accra and Kumasi. The study involved preparation of mortar and cement using

Ghacem Portland cement (Ghana Grey) procured from Ghana and Portland cement (UK Grey) and Snowcrete white Portland cement (UK white) purchased from UK. Clay-free was used as sand and obtained from Portsmouth, UK. The water used was from the Civil Engineering laboratory tap of University of Portsmouth, UK. The assessment was done by comparing the strength properties namely compressive strength, water absorption and dry density of Type I cements from UK and Ghana, in order to find out whether Ghana's cement is of sub-standard or not. They concluded that the quality of Ghana cement is comparable to that of UK, and therefore may not be a contributing factor of building collapses in Ghana. They asserted that further studies on the quality of sand, standard of cement to sand mix ratio in Ghana and the quality of other building materials namely reinforcement bars, timber, aggregate and water are still needed in order to identify which material is of sub-standard and contribute to the collapse of buildings in Ghana. In the same vein, Boateng and Danso (2013) reported that the UK Portland cements (white and Grey) particles are the fineness, with the white being finer than the Grey. The UK Grey cement is deeper in colour than Ghana Grey cement. The Alkali ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ ) content in Ghana cement is more than UK cements while the calcium oxide (CaO) content in UK cements exceeded that of Ghana cement.

Alinaitwe and Ekolu (2014) opined that the causes of collapse of structures in the construction phase among others are: (a) poor materials and workmanship, (b) design and construction errors, (c) absence of professional supervision of site-works, (d) wrong implementation of construction methods, (e) neglect of design approval procedures. They asserted that if the right procedures are followed in the design, construction and operation of the structures, construction failures can be prevented.

A study by Kioko (2014) on the causes of building failure, identified the use of poor concrete mix ratio, poor reinforcement, cost cutting by contractors by changing recommended concrete mix or reducing the amount of reinforcement recommended, among others as the causes of structures collapse in Kenya.

**Table 2.** Reasons for Building Collapse from Real Estate Professionals (Oloyede et al., 2010)

Professionals	Reasons for building collapse					Natural Disaster
	Soil Type	Poor Building design and Planning	Use of Low quality building materials	Use of incompetent craftsmen leading to poor workmanship	Weak Supervision	
Town Planners	30	10	65	70	55	20
Estate Surveyors and Valuers	10	25	75	65	85	10
Structural Engineers	-	35	55	45	55	10
Electrical Engineers	25	40	60	65	55	10
Civil Engineers	35	45	55	45	55	10
Architects	10	10	55	60	35	35
Builders	25	55	25	15	10	45
Building Contractors	25	65	10	10	15	65
Average score in %ages	160/800=20	285/800=36	400/800=50	365/800=46	365/800=46	205/800=26
Ranking	6 <sup>th</sup>	4 <sup>th</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	2 <sup>nd</sup>	5 <sup>th</sup>

**Table 3.** Public Opinion on Factors influencing the Collapse of Buildings (Oloyede et al., 2010)

Factors	Public Perception					Aggregate Score	Ranking
	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree		
Incompetent Contractors	66	18	6	3	7	331	2 <sup>nd</sup>
Faulty construction Methodology	45	20	6	13	16	282	5 <sup>th</sup>
Improper design	-	35	15	3	3	202	7 <sup>th</sup>
Poor Town Planning approval /development monitoring process	-	6	4		90	108	8 <sup>th</sup>
Non-compliance with specifications/standards by developers/contractors	85	5		10	-	375	1 <sup>st</sup>
Use of substandard materials and Equipments	35	45	6	14	-	323	3 <sup>rd</sup>
Inadequate supervision or inspection/ monitoring	51	13	6	18	2	281	6 <sup>th</sup>
Economic pressures	-	11	19	4	66	107	9 <sup>th</sup>
Incompetent conversion, change of use, poor maintenance culture	85	5	5	5	-	285	4 <sup>th</sup>

**Table 4.** Opinion of the Academia on Remote Causes of Building Collapse (Oloyede et al., 2010)

Remote Causes	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Aggregate Score	Ranking
Falling Standard of Education	0	33	26	01	31	150	5 <sup>th</sup>
Lack of continuing Professional development	0	27	32	41	0	163	4 <sup>th</sup>
Non-enforcement of existing laws	88	12	0	0	0	388	1 <sup>st</sup>
Endemic poor work Ethics	61	11	9	19	0	315	2 <sup>nd</sup>
Bribery and Corruption	4	7	4	42	43	164	3 <sup>rd</sup>

In a study conducted in the United States by Kobiela et al (2015) on failures of building structure caused by accidental loads, it is clear that by taking into account the current socioeconomic climate around the world, it is impossible to eliminate completely the risk of building structure collapse.

Oloyede et al. (2010) conducted an extensive research on “Tackling Causes of Frequent Building Collapse in Nigeria”. The methods employed in the collection of data include the administration of questionnaire to professionals involved in the building industry (Contractors, Builders, Architects, Estate Surveyors and Valuers, Civil Engineers, Electrical Engineers, Structural Engineers and Town Planners) among others. The data collected were analysed using descriptive and analytical statistics as shown in Tables 2 to 4. They concluded

that the causes of building collapse were: soil type, poor building design and planning, use of low quality building materials, use of incompetent craftsmen leading to poor workmanship, weak supervision, natural disaster, and corruption among others.

Tchamba and Bikoko (2016) conducted an investigation on “Failure and Collapse of Building Structures in the Cities of Yaoundé and Douala, Cameroon from 2010 to 2014”. The methods employed in the collection of data included the administration of questionnaire to professionals in the building industry (professional engineers, architects and construction professionals), site inspections and case studies for the sites. The data collected were analysed using descriptive and analytical statistics. They reported that the causes of building collapse were: absence of soil investigation and foundation, structural design, detailing, degradation due to environmental factors, use of poor quality materials, concrete processing, excessive loading (Figure 1), structural design, degradation due to environmental factors, Erosion (Figure 2) and other causes. Thus, Tchamba and Bikoko (2016) recommended the following measures listed below to mitigate or ameliorate future buildings collapse:

1. A preliminary geotechnical investigation should be carried out before design. Prohibiting the use of quacks or of non-professionals in building construction.
2. The Cameroonian National Order of Civil Engineers (ONIGC), National Order of Architects (ONAC), National Order of Urbanists and Geoscientists should ensure that only registered and qualified professionals are involved from design stage to completion stage in the construction of future buildings.
3. Professional bodies should hold regular workshops and Continuous Professional Development Programmes (CPDP) for their members to keep them abreast of current developments in their chosen profession.
4. Construction materials quality control check should be made before commencement of using.
5. Getting approval before commencing construction on site.
6. Inspection of construction site should be enforced at the local government authorities and relevant government departments to ensure compliance with approved building plans.



**Figure 1.** Collapse site of a 5-storey building due to excessive loading, Nkoldongo, Yaoundé (Tchamba and Bikoko, 2016)



**Figure 2.** Foundation failure due to Erosion (Tchamba and Bikoko, 2016)

Akinpelu (2002) and Richards (2002) (cited in Oni, 2010) stated that structural failures, environmental changes, natural and human-induced hazards, improper presentation and interpretation in design, deterioration of reinforced concrete occurring as a result of corrosion of reinforcement caused by carbonation and chloride ingress, cracking caused by overloading, subsidence or basic design faults, and construction defects are causes of collapsed buildings in Nigeria.

The Nigeria study on an examination of the incidences of collapsed buildings in Lagos metropolis over a thirty-year period by Oni (2010) showed that causes of building collapses in Lagos metropolis include improper or bad design, construction defects, foundation failure, extraordinary loads, structural defects, dilapidation due to lack of maintenance, use of weak and substandard building materials, and storage of explosive devices.

Olagunju et al. (2013) stated that the incessant collapse of buildings in Nigeria can be minimized if not curbed through adherence to some of the following measures, namely,

“i. Soil test, Environmental Impact Assessment (EIA) and structural analysis needs to be made mandatory to be submitted along with the building plans to planning authorities by all the developers or building approval seekers/applicants, especially for all institutional, commercial and industrial buildings.

ii. All plans for approval must be made to pass through all the professionals associated with building industry working in every State/Local Government Development Control Boards before its final approval.

iii. All plans for approval must be ensured to be in compliance with the Nigeria’s new building code and all the affected local government’s byelaws.

iv. Inspection team must be made to regularly be on the move to inspect all construction works in their locality with the aim of enforcing the building code and the local byelaws.

v. All the professional bodies associated with the building industry in Nigeria, should jointly embark on enlightenment campaign for the public to be aware of the evils behind quarks involvement in building construction activities and the use of low quality materials, untested building materials and local construction methods.”

Kobiela et al. (2015) noted that design errors/faulty design result from the use of improper design methods, the omission of important factors, and not paying due attention to design requirements, e.g. insufficiently understood permanent and operational loads, load

combinations that may occur during either the construction or the operation of the facility. They also classified failures into two categories:

- “Category I includes disasters not resulting from random events, that is human errors – faulty design, performance and operation;
- Category II includes disasters occurring due to fortuitous events, as a result of, among others, the forces of nature (floods, strong winds, heavy snow-falls, lightning strikes, fires), as well as gas explosions, cars crashing into buildings, boiler explosions.”

Figure 3 shows a view of the structure of the roof collapse due to design errors.



**Figure 3.** A view of the structure of the roof collapse due to design errors (Kobiela et al., 2015)

Thornton (1985) (cited in Yates and Lockley, 2002) stated that causes of failures fall into five general areas, namely:

- Design deficiencies
- Construction deficiencies
- Material deficiencies
- Administrative deficiencies
- Maintenance deficiencies

Following the subcommittee held in 1982 in the United States, Dr. Henry Petroski as quoted by Yates and Lockley (2002), a civil engineering professor at Duke University provides the following six factors to help prevent structural accidents from happening:

- Good communications and organization in the construction industry
- Inspection of construction by structural engineers
- Increasing the general quality of design
- Improving the structural connection design details and shop drawings
- Proper selection of architects and engineers
- Timely dissemination of technical data

Yates and Lockley (2002) suggested the following methods listed below for reducing the incidence of construction failures:

- Design and detailing of critical connections by the engineer of record

- Design and supervision of construction of temporary structures by a professional engineer
- Clear definition of responsibility among the engineer, fabricator, and contractor
- Constructability reviews during the design stage
- Full-time inspection of construction by structural engineers
- Education and training of construction teams
- Comprehensive quality assurance/quality control plan
- Structural redundancy in the design to avoid progressive collapse
- Peer review of the structural design and details by an independent professional
- Design engineers should review all shop drawings, shoring, and formwork design
- Construction personnel should be certified for temporary structure design/construction
- Realistic construction schedules (requires education and enlightenment of clients/owners) should be provided
- Structural engineers should review temporary bracing and shoring designs, details, and construction and submit forms to public agencies indicating such review
- Contractor's superintendents should be educated about temporary bracing and stability
- Part-time visitation should be provided by all design principles, not just the structural ones
- Full-time inspection should be furnished by an independent construction professional
- All construction activities should be reviewed prior to the performance of the work by professional engineers with construction experience. This includes the selection and positioning of cranes, concrete pumps, and truck movements
- Site-specific safety plans, which address specific issues that are approved by the engineer, should be furnished. Include any dead loads during construction
- Contractors and subcontractors should be hired based on a prequalification system for quality, safety, and liability
- In-depth inspection should be provided by local authorities rather than cursory walk-throughs
- Stronger supervision should be provided on the part of the contractor to avoid "short cuts" by workers
- Others

Lopez et al. concluded that there is no single strategy, but a multitude of strategies that need to be adopted in congruence to reduce design errors so that safety and project performance can be improved. Further research is required to better determine the strategies needed to significantly reduce design errors in construction and engineering projects (Lopez et al., 2010).

Henneman and Gawlinski (2004), Kaminetzky (1991), Reason and Hobbs (2003), Sasou and Reason (1999) and Stock et al. (2007) (cited in Lopez et al., 2010) have suggested that situational cognitive failures (i.e., thought and planned actions) that contribute to errors can be classified as:

- Skill- or performance-based errors (e.g., the plan is acceptable, yet the actions are not performed as planned);
- Rule- or knowledge-based errors (e.g., the actions are performed as planned, yet the plan will not achieve the outcome intended); and

- Violations or noncompliances (e.g., to industry or organization imposed norms and standards).

In 2012, Windapo and Rotimi examined contemporary issues in building collapse and their implications for sustainable development in Nigeria. To achieve this goal, Windapo and Rotimi appraised the state and severity of building collapse in Nigeria. They reviewed the principles of sustainable development in the built environment, explored whether the approach to construction by industry stakeholders follow the principles of sustainable development and they proposed how the construction industry through innovation and sustainable practices can enhanced sustainable development, growth and resilience of buildings. They reported that incidences of building collapse were prevalent among residential buildings of less than five floors high, and that major commercial centers were worst affected by the under-performance of industry stakeholders. Building collapse in Nigeria is significant and has consequences that cut across the entire spectrum of growth and development. They recommended “an overhaul of planning and implementation policies (e.g., building codes, which set out minimum performance standards for design and construction works that are based on sustainable principles)”.

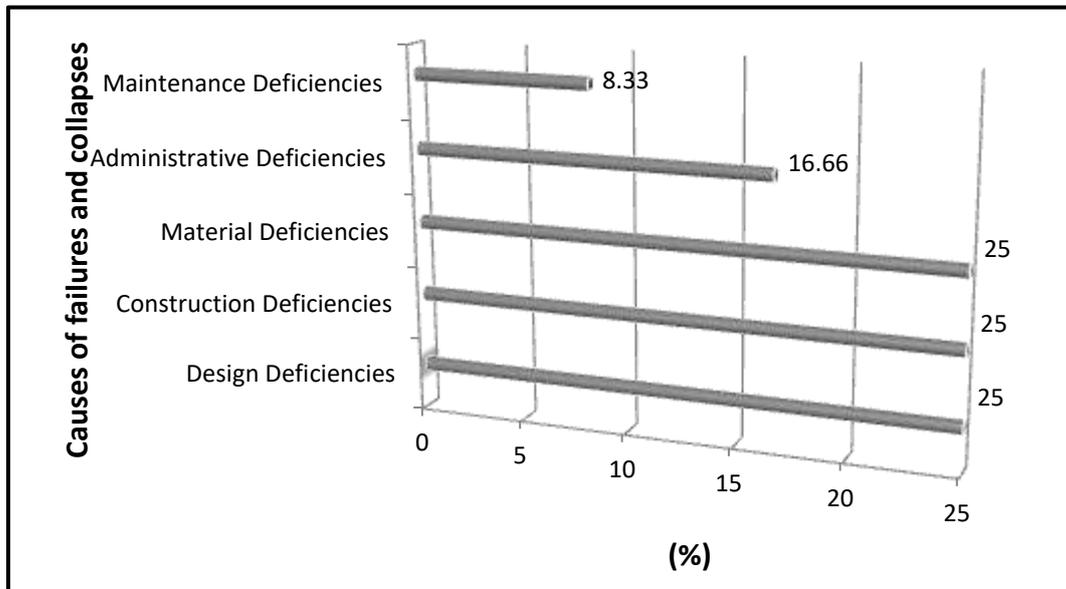
Oseghale et al. (2015) identified and evaluated the causes of building failure and examined the effects of building failure with respect to cost in Lagos State, Nigeria. The study involved collection of data from questionnaire to professionals in the construction industry and case studies for the sites. Descriptive statistical techniques were used to analyze the data. Oseghale et al. (2015) reported that the major causes of building failures were : bad design, faulty construction, over loading, non-possession of approved drawings, possession of approved drawings but non-compliance, the use of quacks, error in design, bad workmanship, bad communication, and flood, lack of maintenance culture, poor quality materials and inadequate fund. They recommended the following factors that would help to checkmate the incidence of structural failure at pre-construction and post implementation phases of building development:

- Strict adherence to code of practice,
- Determination of bearing capacity of soil before design,
- Getting approval before commencing construction on site,
- Building Control Officials should ensure compliance with approved building plans,
- Adequate supervision,
- Carrying out proper site investigation,
- Strict conformance to working drawings,
- Prohibiting the use of quacks and adherence to specification.

Ayeni and Adedeji (2015). Have carried out a study on “Strategies for Mitigating Building Collapse in Nigeria: Roles of Architects and Other Stakeholders in the Building Industry”. The data used were collected through the review of relevant literature, past research works, internet, journals, texts and magazines relating to building collapse in Nigeria as well as pictorial evidences from the six geopolitical zones that make up Nigeria. They reported that building collapse in Nigeria can be attributed to mainly human errors. They have concluded that building collapse can be mitigated through the cooperation and collaborative roles of architects, associated regulatory bodies of architectural profession.

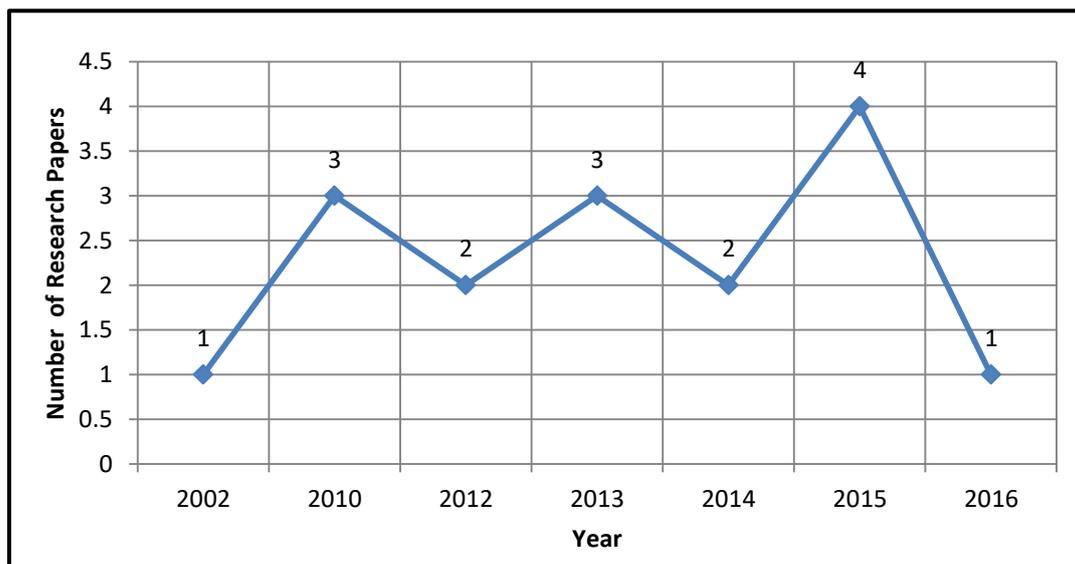
### 3. FINDINGS

Upon review, it is interpreted from the analysis that causes of failures and collapses fall into five general areas, namely design deficiencies, construction deficiencies, material deficiencies, administrative deficiencies and maintenance deficiencies. This review shows that material deficiencies, construction deficiencies and design deficiencies are the most causes of failure and collapse of buildings/structures representing respectively 25% (Figure 4) of the studies, while administrative and maintenance deficiencies represents 16.66% and 8.33% (Figure 4) of the studies, respectively.



**Figure 4.** Causes of failures and collapses

Figure 5 shows the publications related to Failure and Collapse of Buildings/Structures distributed from 2002-2016 considered in this research, it is clear that very few researches were conducted on Failure and Collapse of Buildings/Structures. It can be seen that most of the studies were published in 2015. In year 2010, 2013 and 2015 only three and four research works respectively were published. Apart from this, the below figure also highlights the wide gap in research work related to Failure and Collapse of Buildings/Structures.



**Figure 5.** Chronological order of publication of the reviewed articles

Figure 6 shows the number of peer-reviewed journals and conference proceedings covers research papers which are based on Failure and Collapse of Buildings/Structures, it is clear that the number of peer-reviewed journals welcomes the research works related to Failure and Collapse of Buildings/Structures. Therefore, researchers can use the below graph for selecting the journal for publishing their research work. The top three journals are Civil and Environmental Research, Journal of Performance of Constructed Facilities and Journal of Science of The Military Academy of Land Forces. Civil and Environmental Research is where most articles related to Failure and Collapse of Buildings/Structures are published.

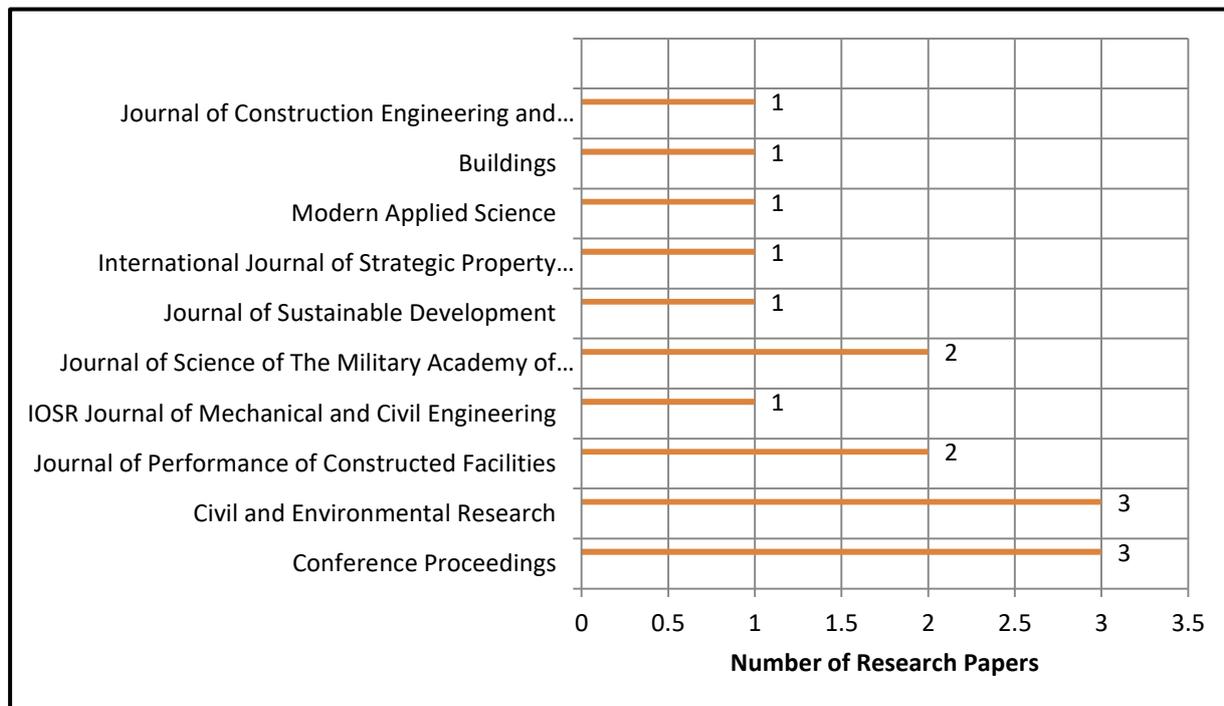


Figure 6. Name of Journals and Conference proceedings and number of research papers

#### 4. CONCLUSIONS

From this review on failure and collapse of buildings/structures, the following conclusions can be drawn:

- Use of poor quality materials or substandard building materials in the construction is the most common cause of building failures and collapsed.
- Most of the studies were published in 2015.
- Very few researches were conducted on Failure and Collapse of Buildings/Structures.
- Causes of failures and collapses fall into five general areas, namely design deficiencies, construction deficiencies, material deficiencies, administrative deficiencies and maintenance deficiencies.

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