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An Investigation into Roof Failures: Causes, Effects and Remedy

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DECLARATION

I hereby declare that this submission is my own work towards the MSc Construction Management and that, to the best of my knowledge, it contains no material previously published by another person, nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

The roofing component of a building affects the long-term quality and life cycle cost of a building. Roof is defined as the topmost covering of a building which provides shelter for the inhabitants or occupants.

Aim of this research is to investigate into the cause, effects and remedies to solve roof failures. Three (3) objectives were developed to assist the realization of the main aim, these are

To identify the causes of roof failures commonly experienced by roof experts, To identify the effects of roof failure, To identify remedies to minimize the incidences of roof failures.

The investigation examined roof styles, types, designs and functional requirements in general and specifically discussed problems associated with roof and roof failure with particular reference to its effects

An extensive literature review was conducted in the construction industry as a whole, basically the roof industry. This review was supported with an in-depth exploratory interview and questionnaire to verify the issue and problems identified in the literature and expand into new area that might not have been given expanded view in literature. Information and results obtained from the in depth literature and survey provided the basis for the selection and development of the Questionnaires as a data collection tool from respondents for the analysis. The questionnaires administered were 30 with a retrieval number of 26 accounting for a response rate of 85%. The Statistical Programme for Social Scientists (SPSS) was used to process the data. The analysed data are presented in the form of tables and figures. Descriptive statistics and mean score ranking was used in the data analysis

The paper identified causes of roof failures to be Design of Building, incompetence of workers, Poor installation, and inclement weather. Categorisation of these roof defects is also defined in this paper. Decreased of property value, cost expenses and structural deterioration are effects identified with roof failure. The paper conclude by laying down recommendations. The paper recommends Good Building maintenance functions as one of the strongest practical remedies that may help in arresting these problems.

Keywords: Pitch roofs, Roof leakages, Proper supervision

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DEDICATION

This thesis is dedicated to the Almighty God.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Roofing as a component of a every building involves a huge investment (Suarez, 1999). The average life span of every roof varies according to the type of material been used (Lewis and Payant, 2000). Roof is defined as the topmost covering of a building which provides shelter for the inhabitants or occupants (Longman Dictionary, 2005), It also protects them and their belongings from the effect of weather conditions such as prevailing wind, sound, rainfall, cold, sun, snow, harmattan etc. (Amasuomo, 2008). According to Mattison (2011), about 15% of newly constructed roofs fail during the first six years of usage. These statistics is as a result of the use of inferior materials, careless installation and overlooked maintenance. The durability of every roofing system depends on parameters, such as: local climate, local temperature which is considered correctly as a result of changes in solar radiation, wind, and other environmental conditions. Another important factor is the resistance to water penetration under rain and deluge conditions (International Conference of Building Officials, 1997). Many attempts have been made to solve roof failure problems in the past. These included the use of various roofing materials, different construction methods, construction of block wall on the roof, the use of different [shapes and planting of wind breakers (Badiu and Bratucu, 2014).

Roof failure can be defined as any form of behaviour in the roof that seems to threaten the safety of the roof in terms of serviceability or which could lead to total collapse (Adesogan, 2018). Roof failures have economic, social and psychological effects on the affected people. Owning a property provides social security and identity as the owner is not subjected to intimidations and insults from landlords. This security could be lost when the roof of a building collapse and rendered unfit for inhabitation (Adesogan, 2018). According to Badiu and Bratucu (2013), defective designs contribute more than 50% of roofing failures, while defective

workmanship accounts for about 30% of same. Other factors include effects from wind and fire, obsolete roofing, poor maintenance, height of the building and the use of cheap and substandard materials (Warseck, 2003; Roberts, 2006).

1.2 PROBLEM STATEMENT

Roof system is an important component of building, its total failure invariably renders the structure over which it is built unsuitable for human habitation (Adesogan, 2018). Problems created out of roof failures are crucial in the development of any community and efforts must be made to minimize and possibly eliminate them. The causes and patterns of roof failures should be clearly understood. An improvement on roofing quality and durability will mean the understanding of the environment, economy, design, construction practices as well as maintenance of roof failure and the exacerbating damages associated with that (Adesogan, 2018). Lack of training on new installation techniques can result in roof failures (Patterson and Mehta, 2011). More often than not, the concept of an integrated building envelope components acting as a single system and the interaction between roof, and environmental forces and other building system are greatly ignored (Lsiburek, 2002).

Majority of roofs are not installed under controlled factory conditions and as a result experience a variety of inherent imperfection (Oliver, 1997; Rivin, 2001). According to Griffin and Fricklas (1995), Technical and economic factors are also causes of some premature roof failures. Khuncumchoo (2007) Budget constraints limit the owner/designer's freedom in selecting the right roofing system for a specific building, resulting in premature of roof failures. Another problem may also be new roof inundating the market. Normal environmental wear and tear damage roof membrane and as such requires regular maintenance. Unlike human skin, roofs do not have a continuous regeneration or self-healing capabilities: schedule preventive maintenance and vigilance is the most suitable solution to increase its life span(Rivin, 2001).

A lot of research has shown roof as one of the most deterioration-prone building component. Therefore, being proactive in the health of a roofing system will ultimately reduce the building financial liability (Suarez, 2005).

1.3 RESEARCH AIM AND OBJECTIVES

1.3.1 Aim

The aim of the study was to investigate into roof failures by identifying its causes and effects in addition to its remedies.

1.3.2 Objectives

1. To identify the causes of roof failures commonly experienced by roof experts.
2. To identify the effects of roof failures.
3. To identify remedies to minimize the incidences of roof failures.

1.4 SCOPE OF STUDY

The research was conducted in Ghana which is situated in West Africa. The study was limited to roof experts in Kumasi, Ashanti Region. This is because of the limited knowledge about the causes of roof failures among residents inhabiting structures with failed roofs (Naoum, 1998). This research was focused on roof installers, roof consultants and roof designers.

1.5 RESEARCH METHODOLOGY

A comprehensive review of literature was conducted from sources like the internet, books, articles and journals. Questionnaires were used as a means of collecting causes of roof failures from roof experts. This is because of the limited knowledge about the causes of roof failures among residents inhabiting structures with failed roofs (Naoum, 1998). Also, it is always

beneficial to have experts in a field to give clarity in an area of study. The goal is to give insight into causes of roof failures that occupants would not normally see. In this study, roof experts are described as a group of people who specialize in all kinds of roofing system and are in the roofing business (Khuncumchoo, 2007) from either designing, maintaining, or consulting. Due to these specific requirements, a pre-defined group of roof experts was selected based on non-probabilistic sampling (Troachim, 2005). By using purposive sampling snowballing technique, a roof expert was targeted and thereby asked to recommend other knowledgeable people who may be interested in participating in the study. In all 30 questionnaires were distributed and 26 questionnaires were retrieved. SPSS was used for the analyzing the results.

1.6 SIGNIFICANCE OF STUDY

The findings of this study will help address the causes of roof failures and its effects on other building components and also on the occupants as well. The whole findings would lead to viable and practically applicable suggestions which would serve as a guide to educate the key role players in the Ghanaian roofing material industry. It will also identify the major factors that causes roof to fail based on the roof experts' experiences. It seeks to identify the appropriate method of fixing roofs so as to bring satisfaction and value for money for customers and overall, prolong the life span of the roofs.

1.7 STRUCTURE OF THESIS

The thesis structure was divided into five (5) interdependent chapters. Chapter one (1) contained the background of study, problem statement, aim, objectives research methodology, research scope and significance of study. Chapter two (2) reviewed the literature in accordance to the aim and objectives. In Chapter 3, the research methodology that was used for this study was outlined and discussed. The empirical analysis of data from the filed survey was discussed

in this section while the final chapter, Chapter 5, conclude the work and gave recommendations which was streamlined towards the research area of this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The chapter entails a review of literature related to the aim and objectives of this study. In this chapter, the definition of roof deterioration is established and the factors contributing to roof deterioration is also discussed with solutions that can aid in eliminating roof deterioration.

2.2 OVERVIEW OF ROOFS AND CLASSIFICATIONS

Hawkins (2012) identifies with the roof or buildings as the most essential component of any structure yet the most neglected and disregarded component. The roof serves as the shelter for life, properties and activities within a building envelope. The roof system serves as the primary sheltering element for the interior spaces of a building. Its structure and construction should control the water flow as well as the passage of air (Ching, 2008). Without the roof, the structure is certainly incomplete. The roof system of a building is one of the most important and the largest investment decision that goes into the building. This is because they are commonly defined by authors as the principal line of defence against the brutal elements of the weather. As such, they are vulnerable to damage and failures being exposed constantly to the elements of the weather. The primary functions of any domestic roof are to:

1. Provide an adequate barrier to the penetration of the elements; and
2. Maintain the internal environment by providing an adequate resistance to heat loss.

A roof must be structured to span across space and carry both its own weight and live loads such as wind and snow. The gravity loads for a building starts on the roof system, therefore structural layout must correspond to that of the wall and column systems through which its loads are transferred down to the foundation system (Ching, 2008).The roof serves as the

waterproof, durable and insulated cover for the structure and are highly prone to damage and failures. The life span of a roof system is significantly affected by its design and construction. A study by Patterson and Mehta (2001) revealed that about 65% of lawsuits brought against building consultants were from the failures of roof systems. With their exposure to the harsh elements of the weather, owners neglect this single most important component and only recognise them when failure sets in and they reach critical conditions demanding high maintenance costs and even an over-haul of the entire system (Ocal and Pancarci, 2010; Toydemir and Bulut, 2010).

Roofing is one of the main components of any building and is relatively a large investment (Suarez, 1999). Many studies have identified roofing as one of the most deterioration-prone building components (NCES, 2003). Therefore, being proactive with the health of a roofing system will ultimately reduce the building financial liability (Suarez, 2005). According to Lweis and Payant (2000), the average life of roofs varies by the type and material of the roof. However, just like any other building component, the life expectancy for roofs is greatly influenced by the presence or absence of a roof maintenance (Suarez, 1999). According to the National Roofing Contractors Association int eh United States, roofs that are not properly maintained will last approximately half of their anticipated normal service life (Suarez, 1999). . All form of roof system- whether flat or sloped, gabled or hipped- have a vital impact on a building's interior ceiling system, and the layout of a building's interior space while shorter roof spans might suggest more rigidly defined spaces. Roof structures and roof materials must have a high level of fire resistance. In addition, the depth of the roof system may have to accommodate mechanical and electrical equipment. Because of its varied functional tasks spread over a large area, the roof system is potentially the most expensive system of a building.

In choosing a roof the economy of the erection and maintenance, durability and thermal insulation values should be greatly considered in the decision-making

2.2 TYPES OF ROOF

All roof systems are generically classified based on their slope. Although several others attempt a classification based on the shapes, materials used, their span and functions, they are commonly classified based on the shapes they present. Agyei (2014) attributes of the life expectancy of a roof and its components to its slope. Although the type of material used, the quality of workmanship involved in its construction, its span over the building and the degree of exposure are all important considerations in extending its life, the slope of the roof significantly contributes to the life span of the roof system. They are hence classified into the Flat roofs and the Pitched roofs.

2.2.1 Flat Roofs

Sometimes referred to as a Low-slope Roof, a flat roof is not as perfectly flat as it is commonly misrepresented to be. These roofs have been around for centuries and are described to have an angle of up to 5^0 to the horizontal. Ancient Syrians and Egyptians used the flat roofs because of the hot sun and lack of rains. (World encyclopaedia, roof). Smith (2011) also defines a flat roof as a roof with a low pitch either less than or equal to 25% slope. They were initially instituted according to Botchway and Afful (2018) due to the building Acts regulating the heights of buildings. They later evolved to become commonly used for roof gardens (green roofs) and the like though at the core they were flat roofs by construction. Due to its lower construction cost and greater capacity to accommodate large complicated layouts, flats roofs are popularly used for commercial buildings (Sereda and Litvan, 1980).

They are framed from rafters laid at a slight angle to encourage the drainage of water ('Basic-Roof-Framing1.pdf', no date). Typically, the flat roof system is comprised of a roof deck and its supporting structure, thermal insulation, retarders for air or vapor and a covering (Khuncumchoo, 2007). Flat roofs are never described as pitched but as laid to fall or, if there is more than one slope, laid to falls, and the fall is given not as an angle but as the fall in millimetres over a horizontal distance in millimetres (Fleming, 2005).

Functionally, these roofs ought to meet three basic functions; insulation, waterproofing and construction. The ponding of water on this type of roof was and continues to be a major problem encountered (Botchway and Afful, 2018).The flat roof assembly aims to overcome this using a water tightness principle that prevents water from the outside entering the roof system (Sereda and Litvan, 1980). Flat roofs in recent times have evolved beyond the basic function required of them in performance to become highly sophisticated in functionality (Botchway and Afful, 2018).

2.2.2 Pitched Roofs

Before the development of the railway system in the nineteenth century the form of roof common to most buildings was pitched roofs dictated by the availability of local material used as roof covering (Barry, 1999). The common roof types in the nineteenth century for pitched roofs were; **thatch**, **tiles** and **slates**.

Thatch: it was common in lowland areas such as Norfolk and Soffolk

As Thatch, Marsh plants, reeds and long straight stalks of water were cut, dried and bound together and laid up the slopes of pitch roofs (Barry, 1999).

Tiles: Extensive beds of clay in midland and southern England, suited to pressing and burning to the shape of roof tiles, provided a ready supply of material for making the small, thin slabs

of burned clay used as a roof covering to the traditional pitched roof form of buildings in the area (Barry, 1999).

Slates: beds of rock that can be split into comparatively smooth plates in rocky upland areas such as Cornwell, Wales, northen England and parts of Scotland, were used as a roof covering (Barry, 1999).

Triangular frames of sloping rafters tied together with ceiling joists, usually with a system of struts were relied on in the construction of pitch roofs. In Ghana for instance, especially in the southern and middle portions where rainfall levels are relatively high Afram (2008) reports of pitched roofs being commonly employed by the natives. Pitched roofs or sloping roofs are mostly common with residential buildings. They may be low sloped or steeply sloped dependent on the construction and functional requirements of the building in consideration. It is important to clarify the difference between the slope and the pitch of a building. Whereas the slope is concerned with the roofing (covering) of the structure, the pitch primarily focuses on the construction of the roof; ergo its carcassing. As such, a common form or type of sloping roofs is the pitched roofs. For design purposes it is worth noting that roof pitches over 70 (degrees) are classified as walls (Chudley & Greeno, 2004)

In its construction, the pitch of the roof is obtained from the concept of a tent construction where several lengths of wood are combined to meet at a central point. At a central ridge majority of pitched roofs with equal slopes are constructed symmetrically to meet. Although this form of construction is relatively more expensive compared to the flat roof, the roof offers more space for services and /or storage. The angle which the general waterproof layer makes with the horizontal is referred to as the pitch . The roof is considered a pitch roof if its angle is above 10(degrees) whiles a roof is considered flat when its angle is less than or equal to 10 (degrees) respectively (Fleming, 2005).

A Sloping roof is more suited for areas with rainfalls and snowfalls due to its run-off ability. Examples of sloped roofs include but are not limited to; the hip roof, the gable roof, the gambrel, the butterfly roof, etc.

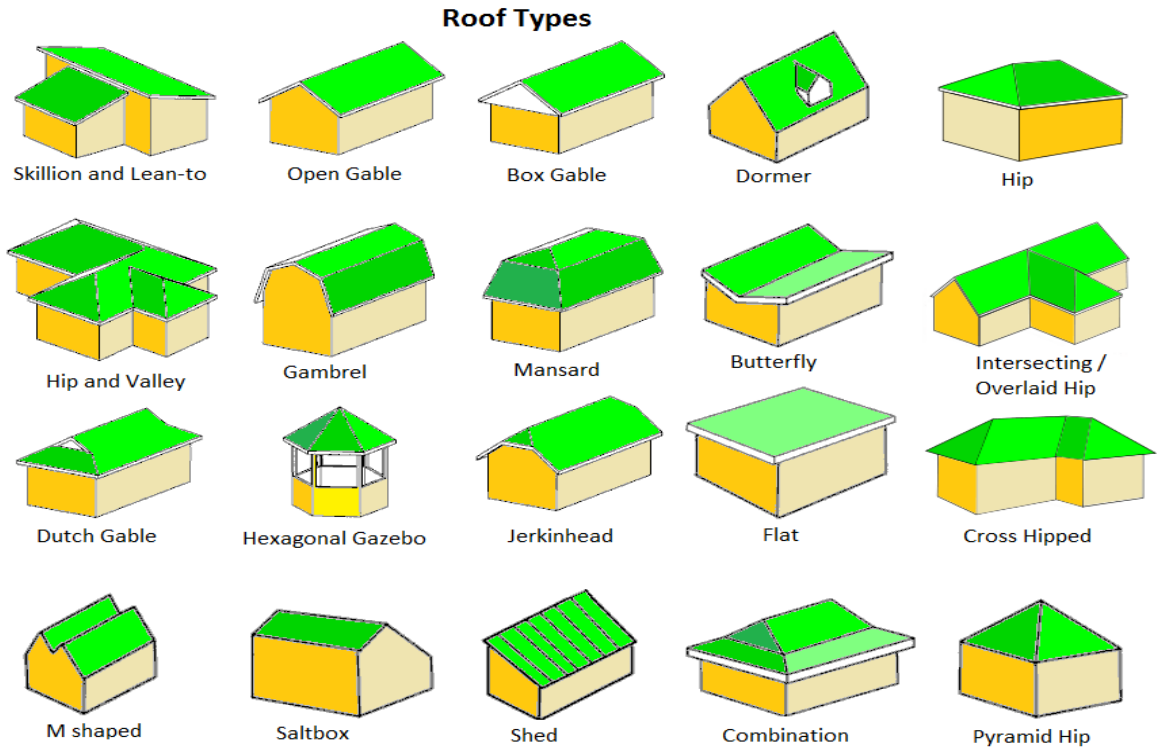

Fig. 2.1 Types of roofs Source : (Botchway and Afful , 2018)

2.3 STEEL ROOF TRUSSES

Steel is stronger than timber for medium and long span roofs and as such, triangulated plane frames called steel trusses carry the purlins to which the roof coverings can be fixed. Being connected securely at their feet by a tie timber the rafters are restrained from spreading by Struts and ties provided within the basic triangle to give it an adequate bracing (Chudley & Greeno, 2004). For steel truss members, angle sections are usually employed since they are a accept tensile and compressive stresses and economical as well. Connection of members of steel truss are done by welding shaped plates called gussets, or together with bolts. 3m to 4.5m

centres are the spacing usually adopted in placing of steel truss which gives an economic purlin size (Chudley & Greeno, 2004).

CONNECTIONS

When structural timber members are join by nails, screws and bolts they still have their limitations . The low efficiency of joints made with a rigid bar such as a bolt is caused by the usual low shear strength of timber parallel to the grain and the non-uniform distribution of bearing stress along the shank of the bolt (Chudley & Greeno, 2004).

TIMBER CONNECTORS

These are designed to overcome the problems of structural timber connections outlined above by increasing the effective bearing area of the bolts (Chudley & Greeno, 2004).

2.3.1 ROOF MEMBERS

RIDGE- This is a pitching plate for the rafters that are nailed to each other through the ridge board it is essential because it serves as the spine of the roof. The ridge board governs the depth of the roof pitch, the steeper the pitch, the deeper the vertical or plumb cuts on the rafters abutting the ridge (Chudley & Greeno, 2004).

CEILING JOISTS- as ties to the feet of pairs of rafters and providing support for the ceiling boards on the soffits and any cisterns housed within the roof void, they fulfil the dual function (Chudley & Greeno, 2004).

PURLINS- Enabling an economic section to be used these acts as a beam, reducing the span of the rafters. In a hipped roof they are metered at the corners and act as a ring beam but in a case of a gable end they can be supported on a corbel or built in, (Chudley & Greeno, 2004).

STRUTS- Within the span of the roof these compression members transfer the load of a purlin to a suitable loadbearing support (Chudley & Greeno, 2004).

COLLARS- To give additional strength, these extra ties are placed at purlin level (Chudley & Greeno, 2004).

BINDERS- To give support to ceiling joists and counteract excessive deflections beams are used and if the span of the ceiling joist exceeds 2400mm (Chudley & Greeno, 2004).

HANGERS- To allow an economic section to be used, vertical members are used to give support to the binders, but if the span of the binder exceeds 3600mm they are included in the design. (Chudley & Greeno, 2004).

2.4 FUNCTIONAL REQUIREMENTS OF ROOF

Architects, Engineers and building owners (clients) all have varying requirements of the roofs of the buildings they put up. Whereas one party requires the aesthetic value and outstanding features to be present, others prefer the roof to function under harsh conditions and yet still others may want the roofs to go beyond providing shelter to serve as storage space. These varying opinions in the functionality of roofs has posed a challenge for writers in determining the functional requirements of roofs that satisfy all known parties to the construction project.

The functional and performance requirement is a statement of the needs to be fulfilled during the service life of a product where this case refers to the roofing system. Booth (1981), Rismmiller (1981)and May (1984) made some efforts to identify performance and functional requirements of roofing systems. They are presented in the table below according to Griffin (1970).

Performance Requirement and Evaluation Tests

Performance Requirement	Applicability				How Evaluated?
	Deck	Vapor Barrier	Insulation	Membrane	
Weather resistance				X	Test
Wind resistance	X	X	X	X	Test
Fire resistance	X	X	X	X	Test
Bitumen flow resistance				X	Test
Appearance				X	
1. Permanent deformation					Judgement
2. Surface defects					Judgement
3. Non-uniform color					Judgement
Thermal insulation			X		Test

FIG 2.2 Performance requirement and Evaluation test

Basically, it is accepted that the roofs serve as the uppermost part of the building is to provide shelter to the structure and its occupants. The functional requirements of each roof are dependent on a varying degree of factors including; the environmental conditions present, the material to be used, the function of the building and the type of roof to be constructed (flat or sloping).

Afram (2008) posits in his work some performance and functional requirements of roof which include but are not limited to the provision of shade to the external walls, insulation against solar heat penetration, shedding of rainwater quickly and effectively, withstanding any superimposed loading (wind pressure, weight of snow, rain), durability and freedom from maintenance and aesthetic appeal. Thus, if done well Sun-shading devices as well as wide over hang could be used to achieve the shading of the external walls., providing a considerable drop in temperature inside the building. Suspended ceiling could also be used to achieve insulation against solar radiation through the roof structure the building.

Nonetheless, literature expands on these basic functional requirements and presents the following requirements to which roofs are expected to conform throughout their serviceable life.

2.4.1 Human Protection

At its core, a roof is to serve this first function of protecting the persons within the structure from the elements of the weather (Chudley & Greeno, 2004). In every part, this function is important as it provides shelter and protection against somethings as basic as bright sunshine, changes in the weather such as the sleet, the hails, rains and high winds. Inhabitants without roof would be subjected directly to these weather changes and consequently suffer the resulting physical ailments from continuous exposure.

2.4.2 Weather Resistance

In as much as the roof is to provide protection, it should be able to stand the elements to adequately perform this function. The roof covering should be able to withstand the effects of weather elements within the geographical location of the structure. Whereas there are different elements present in different regions all over the world, it is important to design roof systems to meet the resistance of the elements present. Common elements to be designed for are the winds, rains, sun and where applicable, snow. Exclusion of rain on the roof is due to the material with which it is covered. (Barry, 1999).

2.4.3 Strength and Stability

In the design of roofs, there are anticipated loads that are catered for in the strength and stability of roofs. This would influence the choice of material, the type of construction and the structural features of the roof system. A roof should be strong enough and stable enough to withstand

loads from the wind and pressure from the atmosphere especially in the case of roofs from multi-storey (high rise) buildings. As a horizontal platform or as a triangular framework, the strength and stability of a roof depends on the characteristics of the materials from which it is constructed and the way in which the materials are formed. (Barry, 1999)

Additionally, where roofs are to be used as storage areas, the framing and components should be designed to meet the maximum weight and loads to be supported by the roof. It is common to find roofs failing in instances where they serve as storage space for Air conditioners, tanks, TV and radio antennas, etc

2.4.4 Heat Protection

The roofs are to serve the additional function of protecting the occupants and other components of the building from heat. This requirement of the roof is particularly important in regions of high heat signatures. Occupants of buildings require the roof to protect them from the blazing heat and as such, roofs in these regions are designed with features that provide cooling effects in times of high temperatures. The various elements of the buildings are also affected by heat and need to be protected from malfunctioning and failures. According to (Suarez, 1999) It is common to find floor boards and panels warping due to intense heat. Walls which undergo intense heat expansion and shrinkage are known to develop cracks and fail. The roofs hence serve a very important function in this respect.

2.4.5 Sound Insulation

To an adequate degree, roofs should provide insulation against sound from external sources. In commercial and industrial areas where noise from the environment is likely to interrupt activities within the building.

2.4.6 Fire Resistance.

A roof regardless of its additional requirements should offer an adequate degree of resistance to fire in order to provide protection to occupants and to the properties within the building as well as the other structural elements of the building. Fire resistance of roof systems prevent the spread of fire to adjacent or connecting buildings and allow occupants enough time to escape should there be such a need. Roofs are required by various building codes to possess a certain minimum fire resistance time to prevent early collapse and allow for occupants to escape thereby ensuring the safety and protection of those within the building.

2.4.7 Day Lighting

Every building requires a certain degree of daylighting to encourage sustainable living within the building envelopes. A such, roofs function as mediums to allow adequate lighting into the structure without letting in the unbearable heat from the environment.

2.5 DEFINITION OF ROOF FAILURE

According to Verhulst et al. (2010), the prevention and infiltration of shed water from the roof assembly into the interior of the structure is the primary purpose of roof systems. Therefore, if moisture infiltrates the interior of a structure the roof system is deemed to have failed. Roofs are not inspected regularly because of the simplicity of carrying out as simple visual inspection which makes small anomalies that are not expected to cause immediate problems turn into water infiltrations due to the lack of corrective actions (Garez et al., 2012). Roof failures has become a common problem on housing quality which affects the use of houses and erodes the main structure of buildings accompanied by challenges to infrastructure maintenance. The failure to detect, identify and correct minor roof deterioration and leakages in its earliest stages is considered the greatest cause of premature roof failure (Graeme, 1989; Lounis, 1998).

According to Verhulst et al. (2010), structural failure of the roof framing, that is collapse of roof is also considered to be roof failure. According to Agoro et al. (2017), roof failures can be categorised into; the entire removal of roof from the buildings which can be called non-collapse roof failure or collapse roof failure where the roof is in place but may suffer one problem or the other that prevents it from maximum performance.

2.6 CATEGORIES OF ROOF FAILURES

According to Adesogan et al. (2018), there are three categories of failures a) Ultimate limit state b) Serviceability limit sate connected with deflection and vibration, c) All other limit state connected with special requirements, for instance, fatigue, fire resistance and water tightness.

2.6.1 Ultimate Failure

This is the structural collapse also known as sudden failure or it could be slow. These types of failures are usually disastrous in nature and are more publicised when they occur than the serviceable failures). This type of failure is the structural collapse of the roof; it may be slow structural collapse known as plastic failure or sudden failure. These types of failures are usually disastrous in nature and more widely publicized than the serviceable failures. An example of ultimate limit state failure is roof blown-off (Park, 2009).

Fig. 2.3 Ultimate Failure of Roofs

2.6.2 Serviceability Failure

These are fairly frequent form of structural failures observed in roofs. They appear in form of deflection and cracks on a structural member, or a breakdown of waterproofing cover which could result into water penetrating the roof, in case of concrete, initiating corrosion of reinforcements and in wood structure, causing decay and eventual deterioration. They could lead to disruption of services and interruption of business activities (Park, 2009).

Fig 2.4Serviceability Failure of Roofs

2.6.3 Special Requirement Failure

This is a functional purpose requirement that has to do with special requirements other than the limit states considered for some special functions other than that of the normal roof functions. For example, in studio design, special precautions are built in the roof to reduce the noise penetration and the acoustics of the roof. The requirement in radiation protection building is to prevent leakage of radio-active elements; here the special requirement is to prevent porosity (Adesogan, 2018).

Fig 2.6 Special requirements failure

2.7 CAUSES OF ROOF FAILURES

There are some factors that are primarily the causes of roof failure while others that may not be primary causes of roof failure can influence roof failure. The primary causes include the topography of the building location, roof geometry, design problems, poor construction and installation practices, lack of maintenance, climatic factors, imposed load on the roof, materials of construction and aging. Factors that can influence roof failure include poverty of the building owner which in many cases makes building owners to seek for bold-off wood instead of good materials to construct, ignorance, topography of the building location and roof geometry.

2.7.1 Design of Building

Without taken into account, many roof designers ignore some design factors such as roof tolerance and safety which end up causing roof failure (Mijinyawa et al., 2009). According to Khuncumchoo (2009), there is lack of knowledge among designers concerning roof specification, roof systems and materials details knowledge. Furthermore, most designers put more attention on the aesthetics with little regard for other factors (Khuncumchoo, 2009).

2.7.2 Materials Inadequacy

A survey conducted by Adesogan (2018) revealed that the high cost of standard structural roofing members causes the would-be house owners who usually employ the services of labour techniques in their projects to go in for off-cuts nd undersized structural timber members which are relatively cheaper but structurally inadequate. The question of resources in labour and materials does not frequently arise in advance countries in sufficient degree to influence choice of structure. In developed countries, however, particularly in ‘emergent’ countries, inaccessible areas, or areas subject to extreme natural phenomena, the question of resources may be extremely relevant (Adesogan, 2018). Local building methods and materials are sometimes

worthy of adoption, particularly when low cost buildings are to be erected. Experiments will indicate the most suitable materials and methods to be used, and these will vary from place to place- steel, concrete bricks and blocks

2.7.3 Poor construction and installation practices

Concrete roof is a self-waterproofing by the use of concrete slabs. If the construction joint is not properly treated leakages might occur. If the concrete is also insufficiently or incompletely vibrated during pouring, the leakages passages will be formed later leading to roof leakages (Pan, 2000). According to Lars et al. (2016), the geographical location (wind) of the actual building are the requirements dependant of the fastening of roofing materials. Also parapet walls are essential for roof performance according to Verhulst (2010). However, poor drainage conditions is associated with many buildings with parapet walls. The roof of a building is one of the most influential element of the evelope in building performance, it can be considered one of the most important element of the a building due to its function status and as such needs quality constructive solution certified by competent bodies , as well as an appropriate design and installation execution (Veiga Morgado 2012)

2.7.4 Competence of workers

Damage to roofing system can be due to substandard construction, often due to inadequate training or supervision during its fixing (Adesogan, 2018). There could also be situations where roofing members are structurally adequate but the mode of erecting is grossly inadequate because of the use of inexperienced artisans. Also roof failures can occur when the roofing sheets are laid in the wrong direction with respect to the direction of prevailing wind thereby encouraging water back splash resulting in leakages (Adesogan, 2018). If this leakage is not rectified immediately, it results in rusting of the fasteners which invariably causes weakening

of the entire roofing system. How local artisans anchor roofs to the superstructure was discovered to be a major cause of roof failures in a research conducted in Kumasi. It was realised that a number of houses had their roofs ripped off during rain storms (Afram and Amos-Abanyie).

2.7.5 Later-Stage service (ageing)

Age equally plays an important role in determining roof failures, an example is when the materials of construction experiences stress reversal for a long time, thereby leading to eventual failure of the roof (Adesogan, 2018).

2.7.6 Inclement of Weather

Crack formation and material fatigue led by periodic vibration of roof material are caused due to the wind. (Mahendra, 1990). A building must have sufficient strength in order to resist the applied loads and prevent wind-induced building failure (Baskaran, 2002). According to Cash (2003), in an investigation conducted revealed that after wind disasters many building failures begin with a component or piece of roof cladding being blown off the building. In conjunction with negative external pressures, internal pressures created by entry of uncontrolled winds buildings can be blown apart. According to Badiu and Bratucu (2014), a well-designed building may be damaged by a wind event that is much stronger than what the building was designed for. Also in the design of roofs, if there is no resistance to the overturning forces of wind as a result of improper design of roof member or little or no consideration paid to roof anchorage, the roof will be prone to blow-off.

2.7.7 Ponded water on roofs

According to Verhulst et al. (2010) ponding on roofs is when rainwater does not drain properly but rather collects at confined spaces and in deflections of the surface of roof. Roof deterioration is accelerated when the weight of the collected water causes significant deflection on the roof frame, thus causing more water to drain to the area and creating instability in the roof framing. . Rain Water is classified as ponding its standing for more than 48 hours, though it may cause problems before that time has lapsed. Water that collects on your roof is often a sign of poor drainage or blocked gutters. If this isn't remedied, you will likely experience leaks and may see structural damage

2.7.8 Abuse, Neglect and Lack of Maintenance

Abuse, neglect, or lack of maintenance that a roof experience during its lifetime can ultimately cause many problems to arise, although improper construction and natural weathering are common reasons for roof failure. The abuse can range from heavy working with inadequate equipments by careless roof installers to heavy foot traffic in areas with little protection on the roof covering (Warseck, 2003). The failure to find and correct minor defects and deterioration in its earlies stages is mostly one of the greatest causes of premature roof failures (Douglas and Ramson, 2013).

2.7.9 Use of Unseasoned Wood

The use of unseasoned wood for roof framing and roof decks with subsequent shrinkage and warping is a frequent cause of premature roof failure (Douglas and Ramson, 2013).

2.7.10 Splitting

Splitting is when cracks appear on the roof or the roof membrane. Splitting occurs at the roof membrane because of its inability of the roof to sustain a certain load as a result from poor workmanship and design (Holmes et al., 2009). Common sources of roof damage like foot traffic , temperature changes and substrate movement become a problem for roof materials since they become less resistant to movement , less resilent and very brittle they age with time. Another reason why splitting occurs is because they were designed poorly which make it impossible to accommodate expansion and contraction of roof joints (Warseck, 2003).

2.7.11 Failure of Flashing

Flashing is a construction detail that is used to seal and protect joints in a building from water penetration (Mohylowski and Jenks, 1993). Joints created by the intersection of the roof and roof mounted structures and projections, such as parapets, hatches, skylights, chimneys among others are the most vulnerable areas of roofing system. They constantly expand and contract in response to changes to humidity and temperature. However, failure of flashing is the major cause of roof deterioration (Mohylowski and Jenks, 1993).

2.7.12 Entrapped and Diffused Moisture

Entrapped moisture in concrete roofs can trap moisture which can cause leakages. The moisture actually seeps through openings. Condensation of moisture may occur in the roof, either waterproofing or within the roofing material (Hanson, 1950).

2.7.13 Lack of supervision

The lack of supervision during the installation of roofs can later generate problems that wold lead to roof deterioration. There is also the issue of inexperienced supervisors in its installation.

Clients often engages the services of carpenters that do not take into consideration the environmental uniqueness of the site coupled with the variances of the roofing materials in roof fixing (Adesogan, 2018).

2.7.14 Local setting (Environment)

The flow of water in roof drains are inhibited by Tree limp or clog by debris. Foreign objects that fall on roofs due to locations and surroundings of the roofs can inhibit the drainage of water from the roof (Khumcumhoo, 2007).Accelerated deterioration of a roofing system and in extreme cases, roof collapse are caused by Poor roof drainage (Verhulst et al., 2010).

2.7.15 Puncture

Carelessness on the part of people visiting the roof: HVAC technicians, window washers, painters, maintenance staff etc are mostly the cause of puntures on roof coverings . (Warseck, 2003). Debris left, blown or tossed on the roof can lead to roof punctures.

2.8 EFFECTS OF ROOF FAILURES

The main and fundamental purpose of a roof is to serve as the buildings defense against elements. Every part of the roof system is vulnerable to damage and leakage. When the roof begins to experience damage and failure a lot and other parts of the building end up being affected.eg a leakage in roof would lead to a damage in ceiling members (Salt lake city 2012). A roof can be said to have certain life span, and if the roof has a required substantial repair before the life spans expiration date then it can be considered to be an unsuccessful or a roof failure (Hanson, 2002). This situation tends to affect the building and the occupants of the building in diverse ways.

2.8.1 Cost Expenses

The sheathing layer of a roof structure serves as the best guard for a building due to its umbrella action of quickly preventing rain water into the building and shielding the building from sunshine and other weather elements. Roof failure has an adverse effect on cost since it could result in loss of fortunes or valuable properties. Further delay actions to replace failed roofs may lead to greater damage of wall structures and other members. Prices of roofing materials are constantly on the rise therefore making cost associated with the repairs of damaged roof enormous and expensive to bear, and even more a stressful burden due to the finding required skills persons to repair (Adesogan 2018).

2.8.2 Decreased Property Value

Affected people of Roof failures encounter social, economic and physiological consequences . Owning a house as an individual provides a form of social security, as the owner is devoid from insults or intimidation by a landlords (Adesogan, 2018). Thus security can be lost when the roof of a building collapse and renders the building unfit for habitation and other economic functions. Greater damage to the wall structure will be experienced if there is a delay in actions to replace collapsed roofs during the rainy season thereby exposing the contents of the house to damage This further goes on to reduce the general value of the building as a whole making it loose its aesthetic and economic value.

2.8.3 Structural Deterioration and Corrosion hazard

Roofs are designed to support certain loads without deforming excessively. The loads are the weights of roofing sheets and objects, the weight of rain and snow and the pressure of wind--called live loads--and the dead load of the roofing materials itself (Mohamme almarwae, 2017). Structural damage is inevitable if there is a serious and long-standing roof

leak. If a good chunk of deteriorated ceiling gives way and falls,anything underneath can be damaged . When the roof is not able to stand this function it tends to be classified as a failure. this goes to have an effect on the structural composition of the building leading to its gradual deterioration, reducing the general safety of the building use.

2.8.4 Slip and fall hazard

A severely leaking roof can cause water to puddle on the floor. you need to get that water mopped up to prevent human fall, , especially if you have children and an active family ,.

2.8.5 Health concerns from mold

According to the U.S. Environmental Protection Agency mold and mildew can lead to serious health issues for occupants with high sensitivity, including nasal congestion, rhinitis, inflammations and asthma, Roof failure resulting from use of inadequate and inferior materials such as unseasoned wood will produce, mold spores and lead to serious health problems like allergic reactions, asthmatic symptoms, and more when present

2.9 MEASURES TO MINIMISE THE INCIDENCES OF ROOF FAILURES

2.9.1 Proper Supervision

During the construction of new roof and re-roofing of existing buildings Proper oversight and supervision can help prevent catastrophic or most extreme roofing failures (Verhulst, 2018).

2.9.2 Epoxy Foam Grout

According to Talib and Sulieman (2011), the selection of waterproofing material can be used based on the level of material exposure to rainwater. Also there is the self-waterproofing of concrete structures which refers to the concrete resistance to water penetration, a measure of

permeability related to compactness of concrete (Shan and Zhou, 2016). According to Talib et al. (2015), epoxy foam grout is the best short term solution for cracked concrete slab by Injecting epoxy using high pressure grouting machine into the concrete.

2.9.3 Fiber Matte Material

Fiber matte is also used to fix concrete roof leakages. The matte is used to patch up the leaking point or line on the concrete and brushed with epoxy coating on top of it to seal the leakage (Talib et al., 2015).

2.9.4 Non-Shrink Cement Grout

Non-shrink cement grout is a type of cement with high strength and does not permit water seepage. It is mostly used at the corner joints between concrete roof and walls where normally cracks occur and thus permit leakages (Talib et al., 2015).

2.9.5 Roofing maintenance

Old buildings deteriorate because due to lack of maintenance. Maintenance essentially refers to preventing rainwater from getting to where it can cause harm. Water has the tendency of entering through the roof, so putting right measures in place to solve minor problems here before they worsen can avert the need for more extensive repair. A roofs average life varies by the type and material of the roof construct (Lewis and Payant, 2000). However, the absence of a roof maintenance programme reduces the life expectancy for the roof, (Suarez, 1999). Over time PVC pipes inserted horizontally in parapet walls enabling rainwater to fall outwards away from the building, accumulate pieces of debris, especially leaves, which are blown out about during the onset of rains (Adesogan, 2018). Inevitable consequence of flooding of the gutters and eventual leakage into interior spaces are caused by the clogging of the PVC pipes. After

the installation of a new roof, it is important to establish a preventive maintenance program in order to attain the expected service life of the roof components. Regular maintenance proactively addresses the conditions that adversely affect roof performance and its components that could lead to the damage of roofing or building components (Canadian Roofing Contractors' Association, 2014). Roof gutters and downspouts must be inspected regularly to checked if they are clogged or there is any debris blocking it and removed (Adesogan, 2018).

2.9.6 Roof Drainage

Appropriate roof drains for the climate and occupancy of the building is the next critical step after the selection of roofing systems (Badiu and Bratucu, 2013). According to Verhulst (n.d) The drainage is the most neglected because its function is often misunderstood by roofers, owners, and even design professionals. Poor drainage has been the ultimate culprit for responsible for roof collapse case.

2.9.7 Regular Visual Inspection

Inspection is a process by which it is possible to guarantee through evaluation and checks, that a given system or service feature in a building corresponds to an acceptable and standard level of required performance (Veiga Morgado 2012)

A simple inspection of roof can reveal obvious signs of problems. Roofs should be inspected for sharp items and fallen debris as they could damage the roof system (Adesogan, 2018). Sharp items could be removed from the roof easily. Check for sagging when inspecting gutters, , because it will prevent water from draining properly resulting in roof failure such as leakages on the wood.

2.10 Building Maintenance Functions

Maintenance and repair, one of the building maintenance and operations subtasks (Cotts 1998), is based on the concept that there are benefits in taking care of built assets to avoid suffering from a malfunction. All built assets gradually lose their performance ability from the time of installation, though at differing speeds. The deterioration rate typically depends on materials, 19 construction means and methods, usage, climatic effects, or geographic conditions. Ideally, the required maintenance tasks begin at the same time the building is built and carries on throughout the building's life. This task can, in theory, optimize expenditures and maximize facilities' value. The maintenance plan is typically based on the fundamental aims and objectives of the organization that owns or occupies the building (Arditi and Nawakorawit 1999b; Vanier 2001). Some organizations plan to temporarily occupy a facility; while others intend to stay in the same building for a long period of time. A maintenance program is necessary for numerous reasons. Basically, maintenance work can and will increase the life of a building and its support systems. The study of IBM buildings in the United Kingdom confirms that even poor maintenance can prevent premature failures of some building components (Kincaid 1994). Building maintenance helps ensure safety and sanitary conditions of building's occupants, as well as continuously meet the designed functions (Wireman 1998). Maintenance also helps make the building acceptable for sociological and psychological reasons. Building maintenance can be classified as "planned" and "unplanned", according to the BS 3811 (Seeley, 1987). Planned maintenance is organized and carried out with forethought, while unplanned maintenance is performed on an as-needed basis. Building maintenance can also be categorized as "predictable" and "avoidable". While predictable maintenance is similar to planned maintenance, avoidable maintenance is to rectify failures caused by poor design, faulty materials, or incorrect installation. Maintenance tasks can be subdivided further, based on the maintenance means or resources required to performed the

work (Magee, 1998), or grouped into boarder categories, such as major repair, periodic maintenance, and routine maintenance (Seeley, 1987).

2.11 SUMMARY

The chapter gave an overview of roofs, the types of roof, roof failure, causes of roof failure, effects of roof failure and measures to minimize roof failures. Among the causes of roof failures, the following factors were discussed; design of building, materials inadequacy, poor construction, competence of workers, later-stage service, inclement of weather, ponded water, abuse and neglect. Also, some of the measures or remedies to minimize the incidences of roof failures were the use of epoxy foam grout, fiber matte material, non-shrink cement, roof drainage and regular visual inspection.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The previous chapter reviewed literature in relation to the aim and objectives and set the pace for the development of a survey from which respondents were sought. This chapter encompasses the research design adopted for this study.

3.2 RESEARCH APPROACH

Saunders et al. (2009) defined research approach selection is tied to the research paradigm. Bryman and Bell (2015) also asserted that, the research strategies used to include the method engaged to undertake these strategies gives description to the complete way to view research approach. According to Saunders et al. (2012) and Bryman and Bell (2015), research approach can be categorized into three separate approaches namely; deductive, abductive and inductive.

3.2.1 Deductive Research Approach

This approach according to Saunders et al. (2012) involves a theory development that has been subjected to a thorough test. Deductive research approach is more centered on hypothesis development that is grounded on other theories, then after tested using a designed research strategy (Wilson, 2010). Thus, this approach of research is the most popular in the natural sciences according to Collis and Hussey (2003). Saunders et al. (2009) postulated that deductive approach to research owes more to the positivism approach especially when it is attached to different research philosophies. Though such classification is misrepresented theoretically and poses no real practical value. According to Baxter and Jack (2008), deductive approach is also known as quantitative method or design. The main characteristic of deductive approach is that facts need to be measured quantitatively after the they have been

operationalized. Additional, with deductive approach, the principle of reductionism is followed (Saunders et al. 2012). The deductive approach is more generic and requires a considerable data (sufficient numerical size). Oppenheim (2003) stressed that, survey instrument such as questionnaires and statistical tests are considered appropriate using deductive approach and key instrument used involving sampling in its data collection to take a broad view of or draw inferences.

3.2.2 Inductive Research Approach

The inductive research approach involves the case where the researcher gathers information for the purpose of developing a theory (Saunders et al., 2012). Inductive research approach is targeted to engender meanings with respect to data set gathered to identify relationships and patterns to build a theory. Again, this approach is primarily tied to the context in which the study's background is placed (Saunders, 2011). Consequently, a small sample of subject becomes more apt as compared to a large sample size. According to Easterby-Smith et al. (2008), researchers are more likely to use qualitative data with inductive approach and employ various methods in gathering data so as to ascertain different opinions of phenomena.

3.2.3 Abductive Research Approach

The abductive research approach is basically used to address the weaknesses accompanying deductive and inductive research approaches. Clearly, with respect to deductive research approach, it is criticized for the lack of precision as to how to select theory for testing in the formulation of hypothesis. Conversely, the inductive research approach is criticized of the view that, no empirical data could essentially facilitate theory building (Saunders et al. 2012). Dudovskiy (2016) asserted that, abductive research approach is not different from the other approaches as it is applied to construct theories and to make logical inferences. Researchers in

most cases stick to the application of deductive and inductive approaches as the application of abductive approach in practice is very challenging.

3.3 RESEARCH DESIGN

Research design is the blueprint for conducting research. According to Yin (2009), it defines the context within which data was collected, processed, analysed and used for the study. A research design deals with a logical problem following a logical structure of inquiry and ensures that the evidence obtained enables one to answer the initial research question as unambiguously as possible, and also attain the main objective of the research (De Vaus, 2001; Yin, 2003). Normally the design specifies which of the various research approaches would be most appropriate and how the researcher plans to implement scientific controls to enhance the interpretability of the results (Polit and Hungler, 1999). The study adopted descriptive study because it is explicitly designed and well-thought-out, and corresponding to the features described in a research question.

3.4 RESEARCH STRATEGY.

Research strategy is an overall design of how to respond to the research questions that have been set (Saunders et al., 2007). According to Yin (2003), the selection of strategy for a research should satisfy three conditions which are the type of research question, the level of control that the researcher exercises over actual behavioral events, and the degree of attention on existing or past events. Case study, experiment, survey, action research, grounded theory, ethnography, and archival research are examples of the research strategies (Fellows and Liu, 2008; Saunders et al., 2009). Denscombe (2007) defined case studies as studies with emphasis on a particular phenomenon with the ultimate aim of providing in-depth account of events, experiences or processes occurring in that particular instances. Cohen et al. (2005) defined

survey as the gathering data with aim of describing nature of existing conditions or establishing standards for which existing conditions can be compared. The selected strategy for this study is survey strategy considering the research questions posed for this study.

3.5 RESEARCH METHODS

A coherent research method stands key for conducting a research. Fellows and Liu (2015) define research methodology as the ethics and measures of logical thought applied to a scientific investigation. The three-advance method of research are: qualitative, quantitative and triangulation/mixed methods. There have always been contradictions on the most reliable and appropriate method in undertaking any research activity. Within the mid of 19th century and 20th century, qualitative research methods have proliferated providing sound and statistical evidence to the field (Chan et al. 2003). Some researchers however have also focused on both the quantitative and qualitative methods to collate relating information with practice by looking for critical success factors, including formulating conceptual and practical models of construction partnering (Cheng, 2001). Consequently, there is the need to view definitions of these key terms (qualitative, quantitative and triangulation/mixed) as employed in this study.

3.5.1 Quantitative Research Methods

Creswell (2009) defined quantitative research method as the means of testing objectives theories by examining the relationships among variables. Li (2012) also asserted that, quantitative research method makes use of experimental methods and thus aims to test hypothetical generalizations for a large sample size. Quantitative research method is considered a systematic research with a structured approach. Again, quantitative research method is employed to measure and as well explain the phenomenon with the use of statistical analysis of the data collected. According to Yin (2015), researchers often employs this method when their objectives is to get answers to the questions like how often, how many, how much etc.

Information which can be numerically examined is gathered by this method , and the findings of which are generally presented using descriptive statistics, graphs and tables. Saunders et al. (2012) stated that, surveys, experiments and use of questionnaires to gather information are made use in quantitative and then revised and tabulated in numbers. In most cases, quantitative research methods are deductive, which involves the development of a theory that is subjected to a thorough test.

3.5.2 Qualitative Research Methods

According to Creswell (2009) qualitative research method is a means for investigating as well as understanding the meaning of groups or individuals assign to a social or human problem. Denzin and Lincoln (2000) stated that, qualitative research includes an interpretative, naturalistic style to its subject matter, subjects' actions and their verbal statements are what is being analyzed for meaningful interpretation. Thus, this method is grounded in practical investigation and evidence. Qualitative research method represents the views and perspectives of the people by establishing the contextual conditions (Li, 2012). Further, it gives insight into present or developing concepts by striving to combine diverse sources of evidence than relying on a single source. They are also framed as case studies and summaries rather than to show a group of numeric data. This method gives answers to questions like what, why and how (Yin, 2015). Open-ended questionnaires or interview guides are normally used in qualitative research.

3.5.3 Triangulation/Mixed Method

An approach or inquiry combining or associating both qualitative and quantitative forms (Creswell, 2009). This approach does not put any limitation on the use of methods across the quantitative and qualitative school and provide complementary advantages (Ng and Han, 2012). Through the use of this method researchers can achieve purposes of triangulation (for

convergence and corroboration), complementarities (employ additional methods for elaboration and clarification), development (employ the result of one method to inform the other), initiation (identification of inconsistencies for reframing), as well as expansion (by employing different methods for different aspects).

3.5.4 Research Methods Used

The research method used for this study is quantitative where questionnaires were used to ask to questions relating to the cause of roof failures, effects of roof failures on occupants and also to suggest some solutions so as to prolong the life span of roofs and prevent premature failure.

3.6 RESEARCH INSTRUMENT

Research instrument refers to tools used for the collection of data during a study. Questionnaire is the convenient tool often used for data collection for its ability to provide cheap and effective data collection in a manner that is structured and manageable (Wilkinson and Birmingham, 2003). Questionnaires could be closed or open-ended questionnaires. For the purpose of this study, the questionnaires were used to gather primary data from the respondents. The questionnaires were structured into section A and section B. Section A would be used to ask questions on the respondent's background. Section B was used to ask questions about the respondents' experience with either roof deign or construction and roof failures. In this section, the respondent was asked to respond to questions relating to the cause of roof failures, effects of roof failures on occupants and also to suggest some solutions so as to prolong the life span of roofs and prevent premature failure.

3.7 POPULATION DEFINITION

Population is defined as a group of individuals to which results, discussion of the results and its implication of the study are to generalized (Sampson, 2012). The population for this study is focused on roof experts. In this study, roof experts are classified as a group of people who are involved in roofing industry and specialize in all kinds of roof systems (Khuncumchoo, 2007) from either designing, maintaining, or consulting. This is because of the limited knowledge about the causes of roof failures among residents inhabiting structures with failed roofs (Naoum, 1998). Also, it is always beneficial to have experts in a field to give clarity in an area of study. The goal is to give insight into causes of roof failures that occupants would not normally see.

3.8 SAMPLE SIZE AND SAMPLING TECHNIQUES

Sampling provides the means by which data is collected from a sub-group rather than the entire population (Saunders et al., 2009). The purpose of sampling is to obtain a manageable size of the population for the study (Kothari, 2004). Sampling techniques are divided into probability sampling and non-probability sampling. Probability sampling is considered as the best because it mitigates the possibility of unrepresentative sample. Non-probability sampling techniques has the likelihood of each case being selected as unknown (Saunders et al., 2009). Probability sampling are simple random, stratified random sampling, systematic sampling and cluster sample (Fellows and Lui, 2008; Saunders et al., 2009). Non-Probability sampling techniques are quota, snowball, purposive, and convenience sampling. Due to these specific requirements, a pre-defined group of roof experts will be selected based on non-probabilistic sampling (Troachim, 2005). By using snowballing technique, a roof expert will be targeted and will thereby be asked to recommend other knowledgeable people who may be interested in

participating in the study. Therefore, the sampling size was 30 roof experts in Kumasi however, only 26 questionnaires were retrieved.

3.9 DATA ANALYSIS

The research would adopt two forms of data analysis which are descriptive and inferential statistics (Naoum, 2013). Graphs, tables, means, modes and charts are used for descriptive statistics. Data processing involves editing the questionnaires, coding and entering them into the computer for analysis. The Statistical Programme for Social Scientists (SPSS) was used to process the data. The analysed data are presented in the form of tables and figures. The questionnaires were coded, then data entered into the SPSS programme, and were analysed. Data from questionnaires will be summarized, coded, tabulated and analysed. Editing will be dome to improve the quality of data coding. Descriptive statistics and mean score ranking will be used in the data analysis.

3.9.1 Test of Validity and Reliability

The quality of the data collected was further tested by checking for the reliability and validity of the data. The Cronbach's Alpha is used in checking the internal consistency of a test scale which is expressed as values between 0 and 1. According to several reports the acceptable range for the alpha values should be between 0.70 and 0.95 (Tavakol and Dennick, 2011)

3.11 ETHICAL CONSIDERATIONS

The study took ethical issues into consideration in order to abide by the ethics of research, Anonymity of respondents are completely assured, names were not required on the questionnaires. It was also not structured in order not to match responses to the actual persons. Respondents were however assured of their privacy, confidentiality, and consent. That was in

the preamble of the questionnaire. Respondents were given true assurance that the information would only be for academic purposes.

3.11 SUMMARY

This chapter described the methodology that will be used for this research by highlighting on the type of research strategy, the population, the sample size, the research instrument and subsequently the research ethics used in gathering data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presented the results and discussion of data obtained from the study. The presentation of the results was arranged in the order of the objectives of this study. The background information of the respondents was presented and the rest of the responses from the respondents were presented and discussed under the heading of the various objectives set for this research.

4.2 DEMOGRAPHIC DATA OF RESPONDENTS

The table 4.1 depicts the biographic information of the respondents where 77% of the respondents were males and 23% of the respondents were females. Again it was found that majority of the respondents had technical training in construction and thus having the required knowledge in roof installation since only roof experts were sampled. The highest respondents were Project officers with a percentage of 23.1% and the second highest was roof installer with a percentage of 19.3%. Most of the respondents had experience in the roofing industry between 0 and 5years. The aim presenting the background information of the respondents who took part in the study was to engender confidence in the reliability of the data collected.

Table 4.1 Demographic Data on Respondents

Background Information	Frequency	Percentage (%)
Gender		
Female	6	23
Male	20	77
Highest level of education	**Frequency**	**Percentage (%)**
CTC I, II, III	9	34.6
HND	4	15.4
BSc	7	26.9
MSc	3	11.5
PHD	3	11.5
Years of experience		**Percentage (%)**
16- 20 years	1	3.8
11-15 years	4	15.4
6-10 years	8	30.8
0-5 years	13	50.0
Current Position Held in the Firm	**Frequency**	**Percentage (%)**
Contractor	2	7.7
Head of Carpentry	2	7.7
Company Architect	2	7.7
Structural Engineers	2	7.7
Foreman	2	7.7
Executive Sale Manager (roofing)	1	3.8
District Engineer	1	3.8
Company Installer	2	7.7

Project Site Manger	1	3.8
Project Officer	6	23.1
Roof Installer	5	19.2

4.3 CAUSES OF ROOF FAILURES

A mean score test was performed to determine the relative importance of each identified variable. The significance level was also set at 95% in accordance with the predictable risk levels. In addition, when two or more variables score the same mean, the highest ranking is assigned to the one with the least standard deviation (Field, 2005). From Table 4.2, both the "age of roof" and "design errors" have the same mean of 4.08. Therefore, the standard deviation of these two factors were used to identify the first highest. From table 4.2, age of roofing elements had the highest standard deviation of about 1.129. According to Adesogan, (2018) age equally plays an important role in determining roof failures, an example is when the materials of construction experiences stress reversal for a long time, thereby leading to eventual failure of the roof. Design of errors ranked the second highest with a standard deviation of about 1.164. Mijinyawa et al. (2009) opined that many roof designers normally fail to take into account some design factors such as roof tolerance and factors of safety, and these could result in roof failure. Unqualified designers ranked the third highest with a mean of 3.85 as Khuncumchoo (2009) asserted that there is lack of knowledge among designers concerning roof specification, roof systems and materials details knowledge. Furthermore, most designers put more attention on the aesthetics with little regard for other factors. The Cronbach's Alpha is used in checking the internal consistency of a test scale which is expressed as values between 0 and 1. According to several reports the acceptable range for the alpha values should be between 0.70 and 0.95 (Tavakol and Dennick, 2011). The results of the validity and reliability test of the data received had an alpha value of 0.792 which falls within the acceptable range.

Table 4.2: Causes of Roof Failures

	Mean	Std. Deviation	Ranking
Age of roofing elements	4.08	1.129	1
Design errors	4.08	1.164	2
Unqualified designers	3.85	1.223	3
Inappropriate specifications	3.81	1.266	4
Defective materials used	3.77	1.366	5
Non-compliance with specification	3.77	1.275	6
Lack of inspection during construction	3.73	1.185	7
Inadequate artisan skills	3.69	1.123	8
Lack of quality management during construction	3.69	1.123	9
Lack of quality management during design	3.62	1.267	10
Contractor errors	3.54	1.174	11
Lack of management of construction process	3.50	1.105	12
Ecological factors (environment)	3.35	1.384	13
Topographical location of building	3.35	1.413	14
Lack of communication between designer and contractors	3.23	1.423	15
Lack of motivation of designer (resulting in forgetfulness or carelessness)	3.15	1.047	16
Inadequate labourer skills	3.15	1.461	17
Unqualified contractors	3.04	1.248	19
Lack of motivation of contractor (resulting in forgetfulness	2.96	1.216	20
Valid N (listwise)			

Reliability Statistics

Cronbach's Alpha	N of Items
.792	19

4.4 EFFECTS OF ROOF FAILURES ON OCCUPANTS AND BUILDING COMPONENTS

A mean score test was performed to determine the relative importance of the effects of roof failures on occupants and building components. From Table 4.3, Increased costs of maintenance for repairs emerged as the highest mean with 4.38. As asserted by Adesogan

(2018) roof failure has an adverse effect on cost since it could result in loss of fortunes or valuable properties. Further delay actions to replace failed roofs may lead greater damage to wall structures and other members. Cost associated with the repair of damage roof could be enormous because of the of the constant increase in prices of roofing materials. Ceiling or deck damage emerged as the second highest effect of roof failures with a mean of 4.23. Drainage effects meaning rainwater would not be able to drain off run as they are supposed to drain thereby causing leakages inside the building. This emerged as the 3rd highest effect of roof failures. Structural deterioration was ranked as 4th with a mean of 3.73. The results of the validity and reliability test of the data received had an alpha value of 0.892 which falls within the acceptable range.

Table 4.3 Effects of Roof Failures

Factors	Mean	Std. Deviation
Increased costs of maintenance for repairs	4.38	1.169
Ceiling or Deck damage	4.23	.992
Drainage effects	3.81	1.297
Structural deterioration and corrosion hazard	3.73	1.041
Walls and insulation hazard	3.62	1.299
Slipping or tripping hazard	3.58	1.238
Loss of security and/or safety	3.50	1.241
Damage of electrical system/components/devices	3.46	1.392
Damage of Floor finishes	3.38	1.098
Health hazard	2.96	1.183
Valid N (listwise)		

Reliability Statistics

Cronbach's Alpha	N of Items
.892	10

4.5 REMEDIES ASSOCIATED WITH ROOF FAILURES

Affected people of roof failures have economic, social, and physiological consequences on them. Here the study sought to identify the remedies associated with correcting roof failures. From Table 4.3, it can be seen that building maintenance function emerged as the highest with a mean of 4.54. Cotts (1998) defines maintenance and repairs as avoiding suffering from malfunction by taking care of built assets. Building maintenance ensure safety and sanitary conditions of building's occupants as well as continuously meet the designed functions (Wireman, 1998). With a mean of 4.50 regular visual roof inspection was ranked as second. This is in line with Adesogun (2018) assertion that roofs should be checked for and sharp items and debris as they could cause damage to the roof system. Compliance with deign specification was ranked as 3rd with a mean of 4.42. This is to say that roof experts with adequate knowledge on the design of roofs must be allowed to design roofs and ensure that that their designs are constructed as such so as to eliminate the design and construction defects that come with roof installation. The results of the validity and reliability test of the data received had an alpha value of 0.904 which falls within the acceptable range.

Table 4.4 Remedies associated with roof failures

	Mean	Std. Deviation	Ranking
Building maintenance Function	4.54	.811	1
Regular visual roof inspection	4.50	.707	2
Roof maintenance	4.42	.902	3
Design to appropriate specification (compliance to standard specification)	4.31	.970	4
Proper Supervision	4.27	1.116	5
Use of quality roofing materials	4.23	1.366	6
Proper Installation (replacement of affected sheets , securing of the field and installation of new flashing)	4.19	.895	7
Qualified Roof designers	4.04	1.216	8
Roof Drainage	4.00	1.095	9
Epoxy Foam Grout (water proofing)	3.50	1.208	10
Valid N (listwise)			

Reliability Statistics

Cronbach's Alpha	N of Items
.904	10

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter gives the summary and major findings of the study, the conclusions drawn from the study and the recommendations made.

5.2 SUMMARY OF FINDINGS

The purpose of the study was to investigate into roof failures by identifying its causes and effects in addition to its remedies. Objectives were set in order to achieve this aim. A descriptive survey design was used for the study by sampling roof experts in the construction industry to answer questions that were designed reflecting each of the objectives that were set. A summary of the findings has been listed below.

5.2.1 Objective One: To identify the causes of roof failures commonly experienced by roof experts

The study revealed that the causes of roof failures are Unqualified designers, Inappropriate specifications, Defective materials used, Non-compliance with specification, Lack of inspection during construction, Inadequate artisan skills, Lack of quality management during construction, Inadequate artisan skills, Lack of quality management during construction, Lack of quality management during design, Contractor errors, Lack of management of construction process, Lack of management of construction process, Ecological factors (environment), Ecological factors (environment), Lack of motivation of designer (resulting in forgetfulness or carelessness) and Inadequate labourer skills and Unqualified contractors.

5.2.2 Objective two: To identify the effects of roof failures on building occupants and other building components

Roof failures have consequences being social, economic and physiological on the affected people. Delayed actions to replace collapsed roofs during the rainy season may lead to greater damage to the wall structures thereby exposing the contents of the house to damage. For the effects of roof failures, it was realized that Increased costs of maintenance for repairs, Ceiling or Deck damage, Drainage effects, Structural deterioration and corrosion hazard, Slipping or tripping hazard, Walls and insulation hazard, Loss of security and/or safety, Loss of security and/or safety, Damage of electrical system/components/devices, Damage of Floor finishes, Health hazard Health hazard.

5.2.3 Objective three: To identify measures to minimize the incidences of roof failures

In eliminating the causes of roof failures, the respondents were asked to identify some of the remedies. The remedies that emerged from the survey were Building Maintenance Function, Regular visual roof inspection, Roof maintenance, Design to appropriate specification (compliance to standard specification), Proper Supervision, Use of quality roofing materials, Proper Installation (replacement of affected sheets, securing of the field and installation of new flashing), Qualified Roof designers, Roof Drainage, Epoxy Foam Grout (water proofing).

5.3 CONCLUSION

The roof is an important part of a building system. The primary functions of roof system is to shelter element in the interior spaces of a building (Ching, 2008). The roof system should be able to control the flow of water as well as the passage of water, air, heat and cold. A roof can be classified be classified into a flat roof and a pitch roof (Fleming, 2005). The classification of a roof is dependent on a number of factors such as the topography of the environment, the weather condition and the choice of the building owner. The functions of any roof is to keep

out rain, wind, snow and dust. It is also to prevent excessive heat loss and to keep the interior of the building cool.

In my analysis, we realize that the major cause of roof failure is the age of roofing elements. This ranked first with a mean of 4.08 and a standard deviation of 1.129. The next major cause of roof failure is the design error which has a mean of 4.08 with a standard deviation of 1.164. Unqualified designers ranked third based on the analysis I did with a mean of 3.85 and a standard deviation of 1.223. This was followed by defective materials used and non-compliance with specification with their mean being 3.77 and 3.73 with a standard deviation of 1.366 and 1.275 respectively. The least ranked cause of roof failure was a lack of motivation of contractors (resulting in forgetfulness). This analysis shows that, the major cause of roof failure is the age of roofing elements. Old buildings tend to have a lot of problems with their roofs causing discomfort to the occupants.

We also realized, that the major effect of roof failure is an increased cost of maintenance for repairs. With the least major effect of roof failure being health hazards.

Based on my analysis, Building maintenance ranked first with a mean of 4.54 and a standard deviation of 0.811. The least ranked was epoxy foam grout with a mean of 3.50 and a standard deviation of 1.208. There is therefore the need for regular building maintenance to reduce the failure of roofs.

5.4 RECOMMENDATIONS

Based on the findings and conclusions the following recommendations are made

1. Regular building maintenance function Building maintenance functions should be a must activity and the utmost priority to curb down and prevent any degree of roof failure

2. Regular visual inspection. Regular visual inspection helps in identifying developing roof problems at its early stage making it much easier to solve them to prevent complete roof failure
3. Regular roof maintenance: Periodic roof maintenance is necessary for every roof structure , tear and worn out roof members should be replaced to ensure a health roof system to increase it life span and prevents its failure
4. Design to appropriate specification (compliance to standard specification) Roof designers should ensure that roof are designed to appropriate specification and standards, complicated roof designs become problematic to work on when the right skilled personel end up not working on them this leads to roof failure and ends up affecting the building users
5. Proper Supervision: During roof installations proper supervision on works done is the best way to help prevent roof failure. Ensuring that the appropriate installation methods are used for the right roof system, appropriate tools and equipment used for their appropriate work and function and also ensure installation works by installers

5.5 LIMITATIONS OF THE STUDY

Like any other, the research had limitations in its conduct and scope which must be acknowledge. These limitations provide basis for future research suggestion

The research limitation are as follow

- The effect of measurement error which might affect the data collection and the kind of analysis to be carried out and the conclusion drawn
- The difficult of gathering the sample of roof experts
- During administering of the survey instrument, persuading the respondents to actually participate in the research survey was the biggest challenge this actually lead to the difficulty in retrieving all questionnaires administered

- Research employed solely the quantitative research method hence making study restrictive, more qualitative method should be employed on the area of study to provide wider perspective to present study

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APPENDIX

SURVEY QUESTIONNAIRE

AN INVESTIGATION INTO ROOF FAILURES: CAUSES, EFFECTS AND REMEDY

Dear Sir/Madam,

I am a post-graduate student pursuing MSc in Construction Management. In fulfilment of the University of Science and Technology's requirements for graduation, I am undertaking a study in roof failures: causes, effects and remedy.

I am therefore soliciting your help by taking a few minutes of your time to respond to our questionnaire which has been designed. Be assured that all information you provided will be treated with the strictest confidence.

Please kindly respond to the following questions by either ticking (√) the appropriate box (es) or by writing your answer in the space provided.

Thank you

SECTION A
DEMOGRAPHIC DATA

1. Gender of respondent
   Male [ ] Female [ ]

2. What is your academic Qualification
   [ ] PHD [ ] HND
   [ ] MSc [ ] CTC I, II, III
   [ ] Bsc

3. For how long have you worked with the company?
[ ] 0-5 years [ ] 6-10 years [ ] 11-15 years [ ]16- 20 years [ ] 21 years and above

4. Current position held in the firm?.....

5. What qualification do you hold in the roofing industry?
   [ ] Architect [ ] Technicians
   [ ] Structural engineer [ ] Project manager
   [ ] Carpenter Foreman

Others, kindly specify……

SECTION B
CAUSES OF ROOF FAILURES

The causes of failures of roofs are varying and dependent on several factors. Below are some causes commonly identified. In your opinion, tick where appropriate the causes of the roof failures on the 5-point scale provided where; ***1- Strongly disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly Agree***

No	CAUSES	1	2	3	4	5
1	Inadequate artisan skills					
2	Unqualified contractors					
3	Lack of quality management during construction					
4	Lack of inspection during construction					
5	Lack of management of construction process					
6	Inadequate labourer skills					
7	Contractor errors					
8	Non-compliance with specification					
9	Inappropriate specifications					
10	Unqualified designers					
11	Lack of communication between designer and contractors					
12	Lack of motivation of contractor (resulting in forgetfulness or carelessness)					
13	Lack of motivation of designer (resulting in forgetfulness or carelessness)					
14	Defective materials used					
15	Lack of quality management during design					

16	Design errors
17	Topographical location of building
18	Ecological factors (environment)
19	Age of roofing elements

SECTION C
EFFECTS OF ROOF FAILURES ON OCCUPANTS AND BUILDING COMPONENTS

Below are some effects of roof failures identified. Kindly indicate by ticking appropriately your opinion on the effects of roof failures on occupants and components of the building. On the 5-point Likert scale***; 1- Strongly disagree, 2- Disagree, 3- Neutral, 4- Agree and 5- Strongly Agree***

No.	ROOF FAILURE EFFECTS	1	2	3	4	5
1	Ceiling or Deck damage					
2	Slipping or tripping hazard					
3	Damage of electrical system/components/devices					
4	Damage of Floor finishes					
5	Health hazard					
6	Structural deterioration and corrosion hazard					
7	Walls and insulation hazard					
8	Drainage effects					
9	Loss of security and/or safety					
10	Increased costs of maintenance for repairs					

SECTION D
REMEDIES ASSOCIATED WITH ROOF FAILURES

Below is a list of common remedies to roof failures. In your opinion on a 5-point Likert scale, kindly indicate the extent to which these remedy point out to impending roof failures. Where***; 1- Strongly disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly Agree***

No.	REMEDIES OF ROOF FAILURES	1	2	3	4	5
1	Proper Supervision					
2	Use of quality roofing materials					
3	Roof maintenance					
4	Roof Drainage					
5	Regular visual roof inspection					
6	Design to appropriate specification (compliance to standard specification)					
7	Proper Installation (replacement of affected sheets , securing of the field and installation of new flashing)					
8	Qualified Roof designers					
9	Epoxy Foam Grout (water proofing)					
10	Building maintenance Function					