The Aesthetics of Structure in Architecture.
A study of force, form and aesthetic response.

Tutor: Kahare Miano

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B02/28509/2009
A man, who becomes conscious of the responsibility he bears towards...an unfinished work, will never be able to throw away his life. He knows the “why” of his existence, and will be able to bear almost any “how”

- Viktor Frankl
DECLARATION

This Thesis is my original work and has not been presented in any other University or Institution for the purpose of awarding a degree to the best of my knowledge. This thesis is submitted in partial fulfilment of the examination requirements for the award of the Bachelor of Architecture degree, in the Department of Architecture and Building Science at the University of Nairobi.

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Arch. Musau Kimeu
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Structural systems have the potential to enrich the aesthetic vocabulary and visual character of a building. However, this link is rarely exploited to its fullest potential. This tends to manifest itself as a disconnect between aesthetic discourses and structural systems, where the focus is on either spectrum with little mediation that touches on how these two aspects can influence each other.

The purpose of this study was to explore mediation links between aesthetic expression and structural form in architecture, through three continuums, namely, force, form and aesthetic response. This was expressed by the following objectives; first, to explore the relationships between structural forms visual characteristics and the forces they convey; second to study the relationship between structural forms and the overall architectural expression of form; and finally, to explore aesthetic response with regards to buildings whose structural systems were exposed or expressed.

The research was carried out using a case study methodology, where three cases within the context of Kenya were studied based on a descriptive framework of form, using variables that were gleaned from the literature review. The study furthermore, incorporated a questionnaire, as a means of gathering information on people’s aesthetic response with regards to the cases selected.

From the findings, three possible meditative interventions were recommended, namely transformation; where dynamic structural forms can be contrasted with rectilinear spatial and enveloping characteristics of Architecture to yield hybrid forms; articulation where controlled but sensitively detailed structural forms can be used to create interest and character within the domain of a dominant spatial or enveloping Architectural form, and finally, optimization, where the innate formal characteristics of structural systems whose forces are visually expressed can be appropriated towards an aesthetic end.
CHAPTER 1: INTRODUCTION
Utilitus; Firmitas; Venustas: Utility; Firmness and Beauty; was the triad of Architectural realisation postulated by Vitruvias in his seminal works De architectura: on Architecture. Utility or convenience where “the arrangement of parts is faultless and presents no hindrance to use”; Firmness or durability where “foundations are carried down to the solid ground and materials are wisely selected”; and Beauty where “the appearance of the work is pleasing and in good taste, where members are well proportioned according to correct principles of symmetry.” (Ten books on Architecture as translated by Harvard University press, 1914)

As we trace the developments in the history of Western Architecture, we are exposed to this unity in a very convincing fashion. Looking at classical orders, we are able to see that technology provided in a clear manner, the vocabulary for aesthetic articulation. Columns, arches, domes, vaults (see figure 1) the flying buttress; all technology geared towards providing structural support were able to be adapted as a source of aesthetic expression to such an extent as to become identifying elements within the orders in which they found expression.

Engineer, Pier Luigi Nervi in his book Aesthetics and Technology, (Nervi, 1966) attributes this intimate unity of aesthetics and technology to “an intuitive knowledge” by the builders of the construction processes of the Architecture they built. He argues that the builders of this pre-industrial age, having limited mathematical means of verifying structural stability, relied heavily on their experience with building materials and the observed behavior of these materials when subjected to forces. They were able to translate this intuitive knowledge into expressive technology which then became a part of the Architectural vocabulary for aesthetics.

A hypothesis by the scholar, Herbert Read, (1960) on the transformation of human artifacts, traces their development through three phases. First they begin as technical objects meant to fulfill practical needs.
They are then perfected and refined to better serve their utilitarian end. Once refined they are then transformed becoming objects of aesthetics in themselves.

This is observable in Architecture as well when applied to the relationships between technology and aesthetics. In Aesthetics and Technology, Pier Luigi Nervi discusses this in-depth: in the tribate structural system of classical orders (see fig 2) columns had capitals and bases whose surface areas were increased in relationship to the column. The Capitol would be made bigger to receive loading from the architrave which would then be transferred to the column, and the base would be enlarged to transfer the load from the column to the ground. Cornices and pediments, he says, evolved from a need to protect the building façade from wear that could be caused by rain, while arches above windows came about from the need for load paths that could redirect the weight from above the window to suitable paths to the ground. These elements are today aesthetic in themselves.

Nervi further argues that the advent of the industrial age brought with it developments in material technology and better refinement of scientific methods. This had the following implications.

1. Lighter and stronger materials such as steel and concrete resulted in the development of structures in which the means of stability could be hidden. The language of force made manifest through technology (structures) was no longer readily visible and apparent.
2. Scientific methods of ascertaining stability through reliable and repeatable mathematical analysis replaced intuitive knowledge of force behavior.
3. A shift in the practice of building brought about a delegation of roles where the Architects forte remained with utilitus and venustas; achieving Architecture appropriate to its purpose, all the while enriching the same Architecture through aesthetics. The Engineers forte, now firmitus, was to ensure that a building stood soundly while adhering to constraints of economy and performance driven design.

Fig 1.0.2: CLASSICAL TRIBATE SYSTEM
Relationships between the capitol, base and column
Source: www.studyblue.com downloaded on 150805 at 0936 am

Fig 1.0.3: SAMUEL BECKET BRIDGE
Santiago Calatrava in Barcelona, Spain
Source: calatrava.com
The combinations of these three factors are possible reasons for the under-utilization of the aesthetic properties of structural systems in contemporary Architecture.

In spite of these factors, this form of expression is not completely removed from our experience. We catch glimpses of it in various manifestations: design interventions of Engineers in way of bridges and towers. These structures are feted to embody elements of “structural art”, a term coined by the scholar David Billington, (1983) pegged on efficiency, economy and elegance. We catch glimpses of this aesthetic in the interventions of Engineer Architects such as Santiago Calatrava (figure 3) and Pier Luigi Nervi. We are exposed to this Aesthetic in the collaborative design efforts of both Architects and Engineers as in the case of Dulles International Airport (figure 5). We therefore know that the aesthetics of structure finds contemporary expression.

Formal Architectural practice in Nairobi has developed in tandem with the occurrences of international trends. The coming of colonial powers introduced western building tenets into our context through education and practice. According to (ETH Studio Basel, 2008) the first occurrences of modernism in Kenya can be traced back to 1935 with the arrival of the German Architect Ernst May, a practitioner within the Bauhaus movement whose buildings include Kenwood building along Kimathi street. Evidence of western influence abounds in Nairobi where a number of buildings can be slotted into the various stylistic developments including neo-classical, modern, and post modern. The contention between technology and aesthetics thus becomes viable in the Kenyan context in as far as there are links between our local architectural expressions and the international climate.

A number of questions come to mind. What types of structural systems do we find in the Kenyan context of Architecture? Do they have aesthetic merit? Can structural form influence the aesthetic experience of Architecture? What would be the physical properties of such structures that had a bearing on buildings aesthetics? Would the structures technical characteristics play a part in the structural forms aesthetic characteristics? Structural systems have an intimate bearing on Architectural form, a major consideration with regards to buildings aesthetics. Therefore given the design rift that removes structure from an Architects design repertoire (in as far as technical aspects of calculation are concerned), how would an Architect interested in harnessing the Aesthetic potential of structural systems go about this task?
Structure has been subject to the dictates of technology, constantly growing and evolving with developments in material technology. It has largely evolved as a means of addressing pragmatic concerns such as achieving greater spans and vertical heights given the material and technological advancements available in a given period of history (Kahuthu, 1997). Having addressed practical concerns however, structure has been seen to transcend just its technical aspects, gaining prominence as an expressive aspect of Architectural orders. This is in keeping with the scholar, Herbert Read’s “hypothesis on the stages of human artifacts: 1. As a tool, addressing a given need or purpose, 2. the perfection of physical aspects that increase efficiency in the given function, 3. The eventual refinement in the “conception of form in itself” “ (Read, 1960)

Kahuthu in the thesis, Structure and Architecture (1997) traces the development of structural systems and begins with “pre-Gothic structures”, these being structural systems predating the advent of gothic architecture. Of historical significance to Architecture was the Post and Lintel system (figure 6) evident in Egyptian, Greek, and Mesopotamian and Roman civilizations. It developed as a rudimentary means of defining, or enclosing space for largely ceremonious functions. The technology available at this time was applicable to masonry and timber. This system was improved upon and eventually reached its pinnacle of expression in the classical Architectural orders, where in addition to practical aspects of support, aesthetic considerations conveying meaning and symbolism yielded various orders: Doric, Corinthian, and ionic, in classical Greek Architecture. ( figure 7)

Following the post and lintel systems was the development of arches, vaults and domes which developed as a means of achieving greater spans over open space.
This system found the height of its expression in Roman classical buildings such as temples and basilicas (figure 8), as well as the aqueducts.

After the arch systems came the buttress systems of gothic architecture in gothic cathedrals. (figure 9). Space and light were crucial aspects of Architecture in this period. Monumental heights together with light invoked a sense of the divine. To achieve these ends, structural elements became tall to increase vertical spans as well as slender to allow plenty of light into the cathedrals. A new challenge presented itself as these slender elements posed a risk of structural instability by possible buckling. They needed reinforcement that would not compromise the experiential qualities of the cathedrals, and this yielded the flying buttress. The flying buttress eventually became an identifying visual element of gothic architecture, transcending its genesis of utility.

With the advent of the industrial revolution, new materials and structural technology came to the fore. Materials such as steel and concrete were now the preferred choice for construction, seen to reflect modern ideals of progress and technology. These materials found early expression in bridges, exhibition halls, railway stations and towers examples including the Crystal palace and the Eiffel tower. A new challenge for the Architectural profession also presented itself as technical aspects of building concerned with the firmness and stability were ceded to the Engineering profession while architects dealt with spatial design as well as form making. This fragmented approach to design yielded, over time, buildings in which structural and architectural elements were largely distinct and separate. A break in aesthetic concerns with regards to the new materials naturally followed as they found expression in technical pursuits of Engineering.
Structural form has the potential to enrich the aesthetic language and experience of Architecture.

Today this link is not utilised to its fullest potential as a means of aesthetic expression. This problem has numerous manifestations. According to Nervi in Aesthetics and Technology, critiques of Architecture focus on either spectrum of these two aspects with little mediation. They explore the aesthetic qualities of buildings with no attempts at understanding the technology through which the architecture is realized, or carry out technical studies that are divorced from the experiential quality of forms of architecture. (Nervi, 1966) According to Lance Lavine in the book “Mechanics and Meaning in Architecture” the problem of unifying technology and aesthetics is manifested as a lack of a metaphorical voice of technology in Architecture. He believes that the human experience is both “symbolic and literal”. Lavine posits that technology should be able to communicate and express our lived experience with natural forces. (Lavine, 2001). According to Author, Andrew Charleson, the problem is more direct, he argues about the plight of structural expression in Architecture, saying “…structure is concealed and nondescript. Where exposed it is repetitive, predictable in plan and elevation with unrefined member and connection detailing that contributes little to Architecture that excites.” (Charlesson, 2005)

Nairobi, which is influenced by the global developments in Architecture, exhibits the same deficiency where the links between technology and the buildings aesthetics are not always readily apparent.

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**PROBLEM STATEMENT**

![PALAZETTO DELO SPORT](http://www.1startgallery.com)

*Fig.1.10: PALAZETTO DELO SPORT: Pier Luigi Nervi,*

*Source: http://www.1startgallery.com. Retrieved 151208 at 12:00 am*
This could be attributed to the fact that structure is largely the domain of the Engineer. Perhaps as Architects, we haven’t come to fully appreciate the relationships between visual and technical characteristics of structure and thus are unable to adequately incorporate these into our initial design repertoire. The issue is further compounded by a proliferation of arbitrary approaches to the manner in which buildings aesthetics is arrived at. The research does not seek to argue against the various methods Architects employ towards the goal of beauty, it does however seek to explore a deeper more holistic approach, where the unity of technology, use, beauty and indeed, meaning, coalesce convincingly in the contemporary Kenyan context.

The optimistic reality that allows us to delve confidently into the research thesis is that the aesthetic potential of structural systems has compelling champions for its cause in contemporary international Architecture as well as cases worth exploring within our local context. This is evident in engineering projects such as bridges and towers, seen to embody elements of structural art, as well as in Architecture where the collaboration of Engineering and Architectural approaches are fused.

The broad objectives of this study are threefold, first: to develop a visual empathy for structural technology. Second: to study structural systems in the context of Architectural cases in a bid to understand the interplay between a structural form and Architectural form; and finally, to explore ways in which these elements associated with hard technology interact with the human spirit by getting to understand aesthetic response and preference with regards to buildings where structure is expressed.
1.4 Research Questions

1. What are the relationships between forces (such as compression, bending, tension) and visual properties of structural form (such as shape, size scale and proportion)
2. What are the relationships between structural form and the overall Architectural form?
3. What is the aesthetic response with regards to buildings whose structure is exposed or expressed?

1.5 Research Objectives

1. To develop a visual empathy for structural principles by analyzing the relationships between structural forms and force.
2. To analyse the relationships between structural form and the overall aesthetic character of Architectural form
3. To analyse and make conclusions on answers to a Questionnaire touching on aesthetic response with regards to buildings whose structure is exposed or expressed.

Finally, having accomplished the objectives mentioned above, the author will seek to suggest guidelines on how one might utilise the properties of contemporary structural systems towards achieving aesthetic effects in the design of Architectural form.
1. Designers have been accused of seeking expressive content outside of the technology that makes it. More critical is a tendency to arrive at Architectural forms arbitrarily, sometimes discounting the contemplation of the technological means by which the desired solution will be realized. This study addresses this concern by exploring the aesthetic qualities inherent in structure as well as by beginning to develop empathy for one of the logics through which Architectural forms and shapes are arrived at: in this case force. An understanding of the relationship between geometric characteristics of structural systems and their force resolving mechanisms can aid designers by first of all tempering the design process from its onslaught on realizable construction logic as well opening up to Architects a range of formal opportunities that may have been hitherto unexplored.

2. The converse scenario also occurs where Architecture is approached from entirely empirical standpoints, resulting in sterile environments that have little empathy or relationship to our lived, tangible and emotional experience of the world. Lance Lavine argues this aspect out convincingly in the Book Mechanics and Meaning in Architecture, and explores ways in which these two seemingly disparate elements, mechanics and meaning, can find common ground within built environments. This issue is pertinent as it brings us back into the realm of holistic design.

3. The Engineers Aesthetic as defined by David Billington is pegged on economy, efficiency and elegance. In an age where sustainable use of resources is at the forefront of discussions, economy in design approach is desirable.
The author intends for this study to be significant in the following ways:

1. The study hopes to encourage a “cross pollination” between the Engineering and Architecture departments within our University through collaborative interaction.
2. The study hopes to uncover multiplicity in the function of Structural elements, which can be appropriated to Architecture. Multiple functioning elements usually imply economy. It is the hope of the author that the methods uncovered will contribute to economic approaches in design and construction.
3. More importantly the author hopes this study’s cases will serve as inspiration to built environment professionals, by encouraging heightened engagement with technology as a source of expressive and aesthetic content.

1.7 Significance

1.8 Assumptions of the Study

1. This study assumes that structure and structural systems posses physical aesthetic characteristics which can be observed and documented.
2. The study further assumes that these physical aesthetic characteristics when exposed can be a vital component in shaping aesthetic response to Architectural form.
1. The study was limited to 3 empirical case studies within the geographical boundaries of Kenya.
2. The scope of aesthetics touched on formal aesthetics as well as aesthetic response and preferences with regards to structures as physical components in Architecture.
3. Three structural systems were evaluated, a braced concrete framework structure, a hyperbolic parabloid concrete shell structure and steel section and reinforced concrete dendriform structure.

The biggest limitation to this study was time, as well as the transient intangible quality of aesthetics which posed a challenge in analysis of aesthetic response. The Eldoret airport also proved to be a complex case study to carry out as a lot of information was withheld on grounds of security. Furthermore, the author experienced challenges in attaining background information for the students centre case study owing its early date of construction and the absence of archival information. The author decided to compliment the students centre case study with a desk study of an Architectural utilising a similar structural system.
Chapter one introduces us to scholarly concepts touching on Aesthetics and structures. It then briefly traces the development of structural systems through the history of Western Architecture, before grounding the enquiry within the Kenyan context. The problem is then stated followed by the objectives the author uses to guide the study.

Chapter two tackles three themes: aesthetics, form, and structural principles. The review on aesthetics seeks to understand definitions of the term aesthetics and help establish a methodological approach. The review on Form first establishes parameters for defining form, before exploring definitions on Architectural and structural form and their possible interactions. The final theme seeks to get a technical grounding on introductory concepts of structures.

Chapter three describes the research methodology that was used to carry out this study. It tackles the research design of the case study approach and gives the criteria the author used to select the cases. It finally describes the methods that were used to analyse and present the data collected in the field.

Chapter four entails the analysis and presentation of the data collected on the three case studies (KICC amphitheatre, Students centre University of Nairobi, and the Eldoret Airport) The case studies are analyzed tempered by the objectives established at the beginning of the study and variables deduced form the literature that help define form.

Chapter five begins by summing up the findings from the case studies analysed in chapter four, based on the research objectives and variables of form established in the literature review. The author then goes on to draw overall conclusions and recommendations based on the findings.