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Historical Review of Sustainability Trends in the Design of Sustainable Research Centres

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The 21st century is an age of global alertness on sustainability as climate change is the biggest environmental problem we face today which has led to a decline in natural resources. This research seeks to review sustainability trends in the design of sustainable research centres, by evaluating the characteristics of these research centres and the principles of sustainability it imbibes as it relates to buildings. A historic research which is a qualitative research method was used for this research work. It includes evaluating the historic developmental growth of research centre designs towards sustainable development using desk study and observations for data collection. The review showed the development of three different trends in design called the Model types. This led to the conclusion that recent research centre designs are geared towards promoting sustainability where symmetry has evolved to favour asymmetry and building materials are becoming lighter with often irregular geometry. Also it houses activities that are more connected to the outdoor environment, thereby producing dynamic spaces with character. The research also shows that as the world tends towards more sustainable practices and heights in construction, practices such as the strategic orientation of structures; choice of building materials; building form; and a more sustainable way of enhancing circulation and ventilation are critical factors of sustainable practices that would shape sustainability principles in the future.

Keywords: Sustainability, Buildings, Form, Research Centres.

Introduction

A research centre on sustainability promotes sustainable living, it is an institution where research challenges in sustainability are investigated, knowledge in technical innovation is broadened and new discoveries related to sustainability evolve (Masdar Institute (MI), 2015). Generally research centre building designs usually have certain group of educational functions complemented by other functions unique to the type of research being conducted at the centre (Office of Facility & Space Planning (OFSP), 2015). A sustainability centre should require that the building itself be sustainable by implementing sustainable goals.

Over the last few years, sustainability has moved from a goal to a necessity in the urban environment. The recent focus of urban planning and urban regeneration practice has been to create sustainable, healthy and viable communities with positive neighbourhood identities (Calkins, 2009). It consists of balancing local and global efforts to meet basic human needs without destroying or degrading the natural environment. Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nation (UN), 1987). Thus, sustainable development's scope is not limited to climate change which is usually supposed as a major environmental issue, but on a broad range of views (Chick & Micklethwaite, 2011). Such as to reduce consumption of non-renewable resources, minimize waste, and to create healthy productive environments which are its main objectives.

Before the establishment of research centres on sustainability, various forms of research centres had been in existence, some as departments of schools in universities and others as independent entities, starting as far back as the 9th century till date (Organisation for Economic Co-operation and Development (OECD), 2011). The research centres started as independent entities, strictly on research, then it evolved into educational institutions, and later it amalgamated to research and educational institutions, then finally in the 20th century all three segments- research sector, educational activities and recreational activities were found to be incorporated in almost all the research centres at the same time as shown in Table 1. For example, around the 9th century concentration was mainly on research observatories, some of which includes; Baghdad (9th Century), Muragbeh (12th century, 1259CE), Ulugh Beg (14th century, 1420) which are research centres of independent entities. Then the 15th century (1550) marked the year of scientific revolution (Hatch, 2002), after which in 1576 Uraniburg Observatory where astronomical researches are conducted was constructed in Sweden (Spotting, 2015). It was strictly a research centre and was also an independent entity (Alistair, 2011). By the 16th century (1645) scientific research became institutional, such as in Gresham College, London. Similarly another scientific institution, the Academy of Sciences in Paris, France was constructed later in the year 1666. This was followed in 1774 by the Russian Academy of Sciences in Moscow (International Institute for Sustainable Development (IISD), 1997). Unlike in the previous years these centres combined research with education.

In the year 1900 research institutes began to develop away from being overseen by the government as separate bodies (OECD, 2011). Research institutes such as the Salk Institute in San Diego, California (Perez, 2010) constructed in 1959 (Jessie, 2014) and the Energy and Resources Institute, New Delhi, India in 1974 emerged. Their buildings utilised various sustainable elements in its design. According to the IISD (1997), sustainability became a globally recognized subject after the Brundtland report "Our Common Future" which was published in 1987. As a follow up to the Brundtland report, a Centre for Our Common Future was established in Geneva in 1988 and subsequent institutions who imbibed some or all the principles of sustainability in their design followed. These include the Institute for Sustainable Development, Canada which emerged in 1990. Two years later in 1992 UN Conference on Environment and Development was held in Rio, after which four years later in 1996, the Centre for Environmental Research and Conservation, Columbia, New York came into existence (Nelligian White Architects, 2015). By the year 2000 the World Summit on Sustainable Development in Johannesburg was held (IISD, 1997). Subsequently centres that sprung up after this summit include CEPEMA Environment Education and Research Centre, Sap Paolo, Brazil in 2007 (Nikolova, 2015). However, in 2009 Omega Centre for Sustainable Living (AIA, 2015), Rhinebeck, New York, Middle East Technical University, Modelling & Simulation Centre (Architizer, 2015), Ankara, Turkey emerged. In the year 2010 Masdar Research Institute, Abu Dhabi, UAE (Foster and Partners, 2015) were constructed. Thereafter in the year 2011 CIRS- Centre for Interactive Research on Sustainability (ArchDaily,2013), British Columbia -Canada was constructed. A year later in 2012 the United Nations Conference on Sustainable Development in Rio took place (IISD, 1997). The sustainable measure implemented by these research centres and their position after key events on sustainability was the reason they were selected to be analysed in this research. Table 1 below shows a timeline of sustainable development and the research centres under study.

Table 1: Timeline of Sustainable Development and Research Centres under Study

Timeline of Sustainable Development				
S/n	**Year**	**Timeline**	**Case Studies**	**Area of Focus**
1.	9th to 16th Century	• Observatories • Baghdad - 9th century • Maragbeh - 12th century in 1259CE • Ulugh Beg – 14th century in 1420		Research
2.	1550	Scientific Revolution		
3.	1576	Uraniburg Observatory, Sweden	Case Study 1	
4.	1645	Scientific research becomes institutional. Gresham College, London.		
5.	1666	Academy of Sciences, Paris, France		
6.	1774	Russian Academy of Sciences Moscow, Russia		Educational
7.	1900	Research Institutes emerges as separate entities away from government supervision.		
8.	1959	Salk Institute San Diego, California	Case Study 2	
9.	1974	The Energy & Resources Institute, New Delhi, India		
10.	1987	Brundtland Report Sustainability becomes a global subject.		
11.	1988	Centre for our common future, Geneva		
12.	1990	International Institute for Sustainable Development, Canada.		Research + Educational
13.	1992	UN Conference on Environment & Development Rio		
14.	1996	Centre for Environmental Research & Conservation Columbia, New York.	Case Study 3	
15.	2000	World Summit on Sustainable Development, Johannesburg		
16.	2007	CEPEMA Environment Education & Research Centre Sao Paolo, Brazil	Case Study 4	
17.	2009	Omega Centre for Sustainable Living Rhinebeck, New York	Case Study 5	
18.	2009	Middle East Technical University, MODSIM - Modelling & Simulating Research Centre Ankara, Turkey	Case Study 6	Research + Educational
19.	2011	CIRS - Centre for Interactive Research on Sustainability British Columbia, Canada	Case Study 7	+ Recreational
20.	2012	UN Conference on Sustainable Development, Rio.		

Source: Author & IISD, 1997

Sustainability in Architecture

According to Chick & Micklethwaite (2011), the three principles of sustainability in architecture includes; Economy of Resources, Life Cycle Design and Humane Design. Economy of Resources relates to the reduction, reuse, and recycling of the natural resources that are keyed into a building while Life cycle design provides a technique for evaluating the building process and its impact on the environment, and Humane design focuses on the relations between humans and the natural world. These principles can provide a broad cognizance of the environmental impact of architectural consumption, both global and locally. Sustainable design therefore involves; using environmentally friendly products, improving indoor and outdoor environmental quality, enhancing site

potential, lessening non-renewable energy consumption, guarding and conserving water and heightening operational and maintenance practices.
Sustainable building is directed towards all phases of the building process as illustrated in Figure 1, starting from the initial planning, to building stage, use and demolition stages and then finally the reuse of the materials (Kim, 2008). A Sustainable building can be said to have been achieved when the opportunities to prevent pollution, exhaustion of resources and attacks on the landscape in all these phases have been used optimally (MI, 2015).

Research Method

The 21st century is an age of global alertness on sustainability (Varis & Maria, 2010) as the world faces the biggest environmental problem─ climate change (Green register, 2014) which has led to a decline in natural resources. This research seeks to review sustainability trends in the design of sustainable research centres, by evaluating the characteristics of these research centres and the principles of sustainability it imbibes as it relates to buildings. This historic research adopted a qualitative research method with an exploratory research strategy. It includes evaluating the historic developmental growth of research centre designs towards sustainable development using Desk study and Observations as data collection tools. This is often used to uncover trends in thought and opinions and dives deeper into the problem (Burns & Robert, 1994), as has been adopted in this research using the historical research technique. According to Groat & Wang (2013), historical research method involves strategic evaluation of past events or items in view, to understand the past, enough to predict the future. Strategically, the principles of historical research employed in designing this research centre, consists of fact finding, organization, evaluation, and logical analysis of evaluations made from past events on research centres.

The study beyond creating a research centre that investigates and educates the populace on sustainability, aims at providing an example of a building that imbibes the principles of sustainability in its design. This was achieved through a method of identifying the characteristics of a sustainability research building (research centre) by examining the principles of sustainability and demonstrating the application of sustainability principles in designing a research centre.

The observation technique used to collect data for this research is the evidence method (Groat & Wang, 2013) which involves studying the historic growth of research centres towards sustainability, through analysing the design features and components of each centre, comparing their commonalities, and finally identifying if any patterns exist. These were achieved through the purposeful selection of eight research centres across the globe presented in Table 2. They have been selected specifically based on the roles they've played in the growth of research centres towards sustainability.

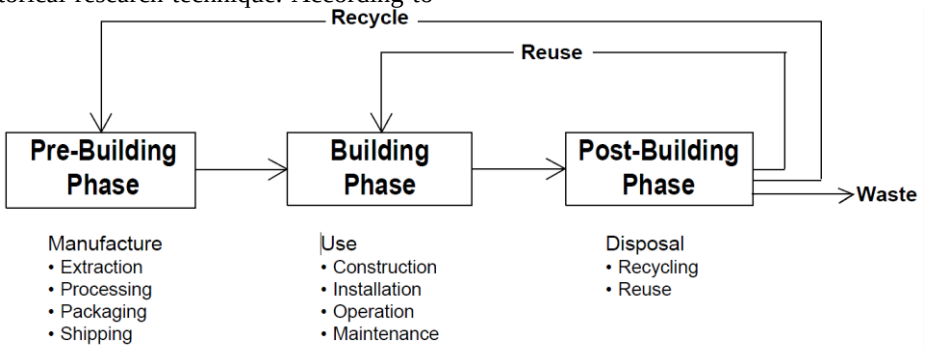


Figure 1 Three phases of the building material life cycle. Source: Kim, 2008.

Each research centre selected came after a significant event on sustainability in time, which affected the design of research centres from that era onwards. Thorough evaluations and tracking of the sources and the features of the selected research centres were achieved using the technique of identification, organisation and evaluation of evidence (Burns & Robert, 1994) and case study tactic of achieving a familiarization with the research centres under study. Further still, evaluation included the use of documentation to verify findings and a comparative analysis of the research centres under study to different conditions, as there are different approaches by people of different cultures and areas (Groat & Wang, 2013). These were all achieved through the thorough observation of variables utilised in the comparative analysis of the institutions examined in this research.

In addition, data was collated and sorted based on the institutions, while the results are presented in tables, diagrams, and charts. Pictures of the institutions are presented as plates to explain further the issues within the discussion of results. The historical development of research centres to date was analysed and shown. This analysis provided illustrations to fully understand the developmental trends of research centres towards sustainability, thereby enabling a prediction of what future trends exist in the development of research centres as well as understanding the principles of sustainability imbibed.

Results and Discussion

The results show that when examined individually the sustainable elements imbibed by each of the research centres vary in terms of their research focus, however when combined and viewed together it shows a growing trend in the development of research centre buildings based on sustainability. A checklist was developed with variables established from previous studies particularly space standards from Neufert & Neufert, (2012) were used to examine the study areas. Explicit details about these for each research centre under study are shown in Table 3 and Table 4.

Table 2 Research centres studied and the main research focus of each centre

S/N	Research Institution	Location	Research Focus	Year
1.	Uraniburg Observatory	Sweden	Astronomy	1576
2.	Salk Institute for Biological Studies	California, USA	Environmental research	1959
3.	Centre for Environmental Research & Conservation	New York, USA.	Environmental research and conservation	1996
4.	CEPEMA Environment Education & Research Centre	Sao Paolo, Brazil	General research on sustainability	2007
5.	Omega Centre for Sustainable Living	Rhinebeck, New York.	General research on sustainability	2009
6.	Middle East Technical University, Modelling & Simulation Research Centre	Ankara, Turkey	General research on sustainability	2009
7.	CIRS- Centre for Interactive Research on Sustainability,	Vancouver, Canada.	General research on sustainability	2011

Source: Author & IISD, 1997

Table 3: Structure of checklist used to examine research centres under study.

VARIABLES (CHECKLIST) USED IN ANALYSIS				
S/N	**Description**	**Area of focus**		**Checklist**
A.	Main components	i.	Plans	• Shape • Arrangement • Function of the spaces
		ii.	Elevations	• Form • Shape • Type • Sizes of openings • Facade ornamentation
		iii.	Sections	• Structural components • Headroom • Internal framework
B.	Design features	i.	Spatial organisation	• Basic components and relationship of the structure
		ii.	Spatial hierarchy	• Understanding strength of the relationship between the spaces
		iii.	Building form	• Its shape • Composing geometry
		iv.	Structures balance, symmetry and proportions	• Buildings balance in relation to its features • Symmetry and proportions
		v.	Enclosure/openness	• Determine whether activities within building are more geared towards enhancing the outside or inside features of the structure.
		vi.	Building material	• Type of materials used on the exterior and interior of the structures
		vii.	Daylight/ventilation	• Type, shapes, sizes and positions of the buildings openings. • Relationship between the buildings orientation and position
		viii.	Energy Efficiency	• Do they use minimal or maximum amount of energy to run the structure. • How do some elements on a building add or reduce to its energy consumption. • Buildings orientation • Type of building materials used, • What unique technique was used to enhance structures energy efficiency

Source: Neufert & Neufert, 2012

Table 4: Structure of checklist used to examine research centres under study.

VARIABLES (CHECKLIST) USED IN ANALYSIS				
S/N	**Description**	**Area of focus**		**Checklist**
C.	Form versus Function	iv.	Plans	• Shape • Arrangement • Function of the spaces
		v.	Elevations	• Form • Shape • Type • Sizes of openings • Facade ornamentation
		vi.	Sections	• Structural components • Headroom • Internal framework and arrangement of the buildings.
D.	Plan versus Elevation	iii.	Spatial organisation	• Identification of the basic components the structure has and their relationship
		iv.	Spatial hierarchy	• Understanding how the connections between the spaces relate in terms of how strong, medium or low the strength of the relationships between those spaces are.
E..	Design features	i.	Building form	• Its shape • Composing geometry
		ii.	Structures balance, symmetry and proportions	• Buildings balance in relation to its features • Symmetry and proportions both on the inside and the exterior.
		iii.	Enclosure/openness	• Determine whether activities within building are more geared towards enhancing the outside or inside features of the structure.
		iv.	Building material	• Type of materials used on the exterior and interior of the structures
		v.	Daylight/ventilation	• Type, shapes, sizes and positions of the buildings openings. • Relationship between the buildings orientation and position
		vi.	Energy Efficiency	• Do they use minimal or maximum amount of energy to run the structure. • How do some elements on a building add or reduce to its energy consumption. • Buildings orientation • Type of building materials used, • Technique was used to enhance structures energy efficiency

Source: Neufert & Neufert, 2012

Features of a Sustainable Building

Essential features of a sustainable building include; energy efficiency, materials, water minimisation hierarchy, social and economic impact (Green Register, 2014). These features were used to examine the level of sustainability principles each building imbibed in its design.

Energy Efficiency of the Research Centres under Study

Elements in terms of energy efficiency deduced from the cases studied are that energy efficient buildings are usually compact; and have air tight external envelopes with possible ventilation. The research centres tried to achieve maximum natural daylight by using solar energy - which is free, carbon neutral and unlimited. Orientation plays a big role in energy efficiency, with buildings oriented to gain maximum passive solar energy while also shading from excessive solar gain.

These deductions were made based on the elements observed from the research centres studied, such as: The compact u-shaped geometry of Centre for Interactive Research on Sustainability, the symmetric square form with a central atrium of Middle East Technical University, Modelling and Simulation Centre, the compact plan with a central lounge of CERC (White, 2015), and finally the fact that Omega Centre for Sustainable Living's achieve maximum utilisation of daylight through the use of clerestory windows, solar panels were used to generate electrical energy and that maximum light and ease of ventilation was achieved by using a window wall and operable windows.

Building Materials Used in the Research Centres under Study

In terms of building material usage in the research centres studied, it was deduced that a building is termed sustainable if it is characterised by the use of locally sourced building materials, and the building specify natural materials with low volatility and low embodied energy. These buildings are usually designed using the waste minimisation hierarchy by reducing the amount of materials used and considering whether they are recyclable, can be reused or reclaimed.

These deductions were made based on the elements observed from the research centres studied, such as the high- tech façade elements used for Middle East Technical University, Modelling and Simulation Centre, and Centre for Interactive Research on Sustainability and Masdar. The simple exposed elements used in Salk Institute for Biological Studies and Cepema Environment Education and Research Centre. Also, these simple elements are used on the Omega Centre for Sustainable Living's use of reclaimed and recycled building materials in construction.

The Use Of Water Recycling In Research Centres under Study

In terms of water usage, it can be said that a building is termed sustainable if it utilises water-saving building elements, rainwater harvesting and grey water recycling systems. The building should use permeable landscaping materials to allow water to percolate and replenish the local water table, while landscaping with native plant species. These deductions were made based on the elements observed from the research centres studied, such as: the green roof and water management system of Centre for Interactive Research on Sustainability, presence of an aerated lagoon, a butterfly roofline to capture rain water, a water filtration bed and outdoor planters in Omega Centre for Sustainable Living.

Social and Economic Impact of Research Centres under Study

The social and economic impact of a structure from the research centres studied indicates that a building is termed sustainable if it provides jobs for the community, considers its effect on the community and educates its users on sustainable measures in a collaborative and practically oriented way.

These deductions were made based on the elements observed from the research centres studied, such as: The Centre for Interactive Research on Sustainability's open centre provided for community interaction, common room, auditorium and the bicycle parking spaces provided along the entrance axis spaces within the building. The semi-open social spaces provided in Cepema Environment Education and Research Centre (Buildings, 2015), and the community participation encouraged in the Omega Centre for Sustainable Living (BNIM, 2015).

Comparative Analysis of the Research Centres under Study

An in-depth comparative analysis of the research centres under study illustrates the relationship that exists within the changing trends in the development of research centres across time as shown in Tables 5-7. The analysis of the research centre design configurations are shown as well as the trend in evolution of a new typology of building forms called the Model types.

Table 5: Analysis of Design Features Research Centres

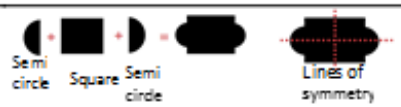
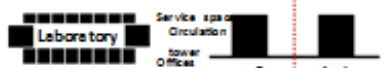
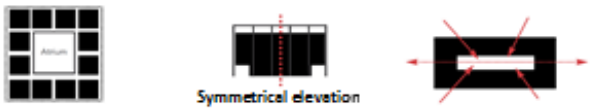
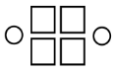
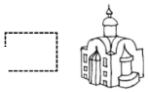
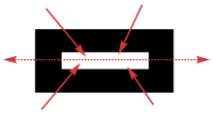
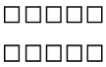
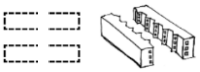
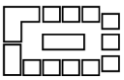
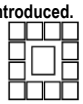
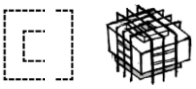
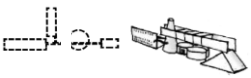
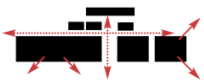
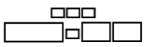
SUMMARY OF ANALYSIS - DESIGN FEATURES			
TIME PERIOD	CASES	DESIGN FEATURES	MODEL TYPES
8TH -18TH CENTURY	Case 1 Uraniburg Observatory		TYPE 1 • Compact form • Mostly symmetrical • Uses pure forms • Activities more focused towards inside
20TH CENTURY	Case 2 Salk Institute For Biological Studies		
	Case 3 Centre For Environmental Research & Conservation		
21ST CENTURY	Case 6 Middle-East Technical University, Modelling & Simulation Research Centre		
	Case 4 Cepsma Environment Education & Research Centre		TYPE 2 • Linear form • Asymmetrical • Plays with form • Activities are more connected to the outdoor environment
	Case 5 Omega Centre for Sustainable Living		
	Case 7 CIRS - Centre for Interactive Research on Sustainability,		TYPE 3 • U- Shaped compact • Plays with form • Symmetrical + Asymmetrical • Connected to outside

Table 6: Analysis of the Plan versus Elevation and Form versus Function of Research Centres

ANALYSIS - Plan Versus Elevation And Form Versus Function				
Time Period	**Cases**	**Plan Versus Elevation**		**Form Vs Function**
9th -16th Century	**Case 1** Uraniburg Observatory	 Square based plan	 Elevation with	Building's form is a direct result of its function as an astronomical talisman.
20th Century	Case 2 Salk Institute For Biological Studies	 Linear, symmetric	 Symmetrical linear	Building's form is a result of wide open laboratories at the centre of each wing.
	Case 3 Centre For Environmental Research & Conservation	 Compact plan	 Compact elevation	Building's form is a result of spatial organisation to maximize day lighting at its centre.
21st Century	**Case 6** Middle-East Technical University, Modelling & Simulation Research Centre	 Symmetrical square plan	 Symmetrical square elevation	Building's form is a result of the need for flexibility in the research areas.
	Case 4 CEPEMA Environment Education & Research Centre	 Plan combines geometries	 Elevation combines	Building's form with cone and triangle not reminiscent of functions within them.
	Case 5 Omega Centre for Sustainable Living	 Linear plan	 Linear elevation with butterfly	Building's form is a result of its aerated lagoon, maximum day lighting & rainwater collection.
	Case 7 CIRS- Centre for Interactive Research on Sustainability,	 U-Shaped plan	 Line of symmetry	Building's form is adapted for multiple sustainable practices, such as the water management system.

Source: Authors, 2017

Table 7: Comparative Analysis of the Development Change of Structures in Relation to its Features

Model Types	Cases	Change in Design Features	Development
Type 1 • Compact form • Mostly symmetrical • Uses pure forms • Mostly enclosed spaces	**Case 1** Uraniburg Observatory	3 floors with rooftop observatory 	Compact and simple enclosure, as just one entity. The form of the building follows function. 
	Case 2 Salk Institute For Biological Studies	6 floors of research labs, accommodation removed 	Linear nd housed within two separate ntities 
	Case 3 Centre For Environmental Research & Conservation	2 floors of research labs, library & lounge introduced 	Level of nclosure increased. Compac linear and enclosed as one enti . 
	Case 6 Middle-East Technical University, Modelling & Simulation Research Centre	3 floors of flexible Research space, Offices, library, and Gallery introduced. 	Level of nclosure reduced by havin a central atrium with skylight. 
Type 2 • Linear form • Asymmetrical • Plays with form • Encompasses different levels of enclosure	**Case 4** CEPEMA Environment Education & Research Centre	2 floors of research labs, classrooms and support spaces, accommodation re-introduced. 	Level of nclosure maintained for only the abs. 
	**Case 5** Omega Centre for Sustainable Living	1 floor of an eco-machine with semi- outdoor classrooms. 	Level of nclosure reduced to make it ore community oriented. 
Type 3 • U- Shaped compact • Plays with form • Multiple levels Of enclosure • Connected to outside 	**Case 7** CIRS- Centre for Interactive Research on Sustainability,	3 floors of research labs with added support spaces and cafe introduced to foster student life. 	Level of nclosure flexible to accomm date different user types (c ildren, university students researchers and Professi nals). 

Deductions from Summarised Analysis Made On Research Centres Studied

Analysis carried out on all the chosen research centres has shown that, it is necessary that when designing any research centre on sustainability, the building be provided in such a manner that it is of plausible architectural complexity. It should provide functions and elements that are present in the research centres analysed, as well as serve as a public-oriented building that can be utilised by several members of the community in order to promote, educate and ensure that sustainable living practices are carried out and appreciated by the current generation. It means that any

element or feature that adds to the value of a structure and does not affect man and its environment negatively can be said to be following the principles of sustainability.

Evolution of Various Types of Research Centre Building Design Models

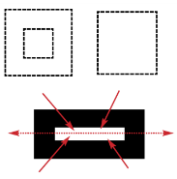
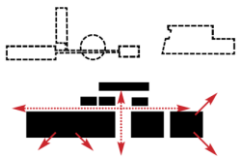
The Development of Implicit Pattern called the Model types based solely on the Institutions' Building form where discovered in this research, three typologies were noticed from the features deduced and subsequently described in the proceeding section. Model Type one (1) models are of compact form, mostly symmetrical, uses pure forms, and have activities more focused towards the inside, Model Type two (2) are of linear form, asymmetrical, plays with forms and have activities that are more connected to the outdoor environment, Model Type three (3) models include the centre CIRC, which consists of a u-shape, being compact, playing with form, symmetrical and asymmetrical and connected to the outside (see Table 5 to 8).

Essential Sustainable Strategies in Designing Sustainability Research Centres

The sustainable strategies that can be incorporated in the design of any research centre in order to promote sustainability include putting the structures economic factor in view. This could be attained through the use of reclaimed and recycled building materials, thus creating a cost effective building. Also by the inclusion of spaces like a recycling centre, multipurpose hall, crafts studio, workshops or any space that communal services can be rendered. In this case users and the community can be educated on sustainable measures in a collaborative and practically oriented way. The design can also support sustainability by enhancing the building envelope through shading parts of the structure, walkways, the building and its roof using photovoltaic panels to generate solar energy, and by creating a façade that is shaded by moveable shade louvers. Through orienting the building in such a way that maximum passive lighting and natural ventilation is achieved while providing shade to intricate parts of the building. Utilising water-saving building elements, rainwater harvesting and grey water recycling systems can be used to promote a building's sustainability.

Furthermore, planting diverse vegetative species in landscaping, which will enrich the soil and help in channelling prevailing winds through the structure, and using permeable landscaping materials can also be used to allow water to percolate and replenish the local water table, thereby serving as another method that can be used to promote sustainability in buildings. Sustainability is a broad subject, therefore recommendations for further research is to concentrate on the different aspects of sustainability such as building materials, building form and energy efficiency as a single entity.

Table 8 Explaining the characteristics of the three model types that evolved from the research.

TYPE 1	TYPE 2	TYPE 3
• Simple geometric plans and elevations. • Form of the building as a result of the functions happening within.	• Linear geometric plans and elevations. • Form relevant to main functions.	• U-shape plan and elevation. • Buildings form enhances sustainable practices.
		

Conclusion

The historical overview of the development of research centres towards implementing sustainable strategies in their design showed a development in the implicit pattern of these institutions form. It showed the growth of three different patterns called the Model types. Model type one (1) were of compact form, mostly symmetrical, uses pure forms, and have activities more focused towards the inside, Model type two (2) are of linear form, asymmetrical, plays with forms and have activities that are more connected to the outdoor environment, Models Type three (3) consists of a u-shape, being compact, playing with form, symmetrical and asymmetrical and connected to the outside. This shows that the older and earlier structures had a more compact building envelope and used building materials that were easily accessible in the region, such as bricks, having the building envelop looking visually heavy.

Therefore, it is established that recent research centre design tends towards promoting sustainability where symmetry has evolved to favour asymmetry. Also building materials are becoming lighter with often irregular geometry while also having activities that are more connected to the outdoor environment thereby producing dynamic spaces with character. Being a research centre promoting sustainability, the buildings themselves should be sustainable by implementing sustainable principles.

Conclusively, the research has shown that as the world is moving towards more sustainable practices and heights in construction, practices such as the strategic orientation of structures, choice of building materials, building form, a more sustainable way of enhancing circulation and ventilation, are key factors of sustainable practices that would shape future sustainability principles.

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