SHAPE GRAMMAR BASED ADAPTIVE BUILDING ENVELOPES:

Towards a Novel Climate Responsive Facade Systems for Sustainable Architectural Design in Vietnam

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Declaration

I certify that this thesis is my own work, based on my personal experience and research. All materials and sources used in its preparation, whether they are books, articles, reports, and any other kind of document, electronic or communication, have been acknowledged. I also declared that I have not copied in part or whole or otherwise plagiarised the work of other students and/or persons.

Glossary of Terms

AEC	Architecture Engineering and Construction
API	Application Programming Interface
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Modelling
BPA	Building Performance Analysis
BPO	Building Performance Optimisation
BREEAM	Building Research Establishment Environmental Assessment Method
BGS	BIM-based Generative System
BSM	BIM-integrated Simulation Methods
CBDM	Climate-based Daylight Modelling
CSV	Comma-Separated Value
DOE	Department of Energy
DMS	Dynamic Thermal Simulation
GBS	Green Building Studio
GUI	Graphical User Interface
gbXML	Green Building extended Markup Language
HVAC	Heating, Ventilating and Air Conditioning
IES	Integrated Energy Systems (from DOE)
IES-VE	Integrated Environmental Solutions – Virtual Environment
IDEA	International District Energy Association
IEA	International Energy Agency
IFC	Industry Foundation Classes
IPCC	Intergovernmental Panel on Climate Change
LEED	Leadership in Energy and Environmental Design

MOO	Multi-Objective Optimisation
NOAA	National Oceanic and Atmospheric Administration
OPEC	Organization of Petroleum Exporting Countries
UNFCCC	United Nations Framework Convention on Climate Change
VGBC	Vietnam Green Building Council
WGBC	World Green Building Council

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Dedication

To

My mother Bich Lam, my sister Huong Thao and my wife Anh Thu, with my gratitude for their unconditional love, kindness and belief which have enriched my soul and strengthened my ability me to undertake and accomplish this research.

Abstract

The concept of a dynamic building enclosure is a relatively novel and unexplored area in sustainable architectural design and engineering and as such, could be considered a new paradigm. These façade systems, kinetic and adaptive in their nature, can provide opportunities for significant reductions in building energy use and CO2 emissions, whilst at the same time having a positive impact on the quality of the indoor environment. Current research in this area reports on a growing increase in the application of new generative design approaches and computational techniques to assist the design of adaptable kinetic systems and to help quantify their relationships between the building envelope and the environment.

In this research, a novel application of shape grammar for the design of kinetic façade shading systems has been developed, based upon a generative design approach that controls the creation of complex shape composites, starting from a set of initial shapes and pre-defined rules of their composition. Shape grammars provide an interesting generative design archetype in which a set of shape rules can be recursively applied to create a language of designs, with the rules themselves becoming descriptors of such generated designs.

The research is inspired by traditional patterns and ornaments in Vietnam, seen as an important symbol of its cultural heritage, especially in the era of globalisation where many developing countries, including Vietnam, are experiencing substantial modernist transformations in their cities. Those are often perceived as a cause of the loss of both visual and historical connections with indigenous architectural origins and traditions. This research hence investigates how these aspects of spatial culture could be interpreted and used in designing of novel façade shading systems that draw their inspiration from Vietnamese vernacular styles and cultural identity. At the same time, they also have to satisfy modern building performance demands, such as a reduction in energy consumption and enhanced indoor comfort. This led to the exploration of a creative form-finding for different building façade shading configurations, the performance of which was tested via simulation and evaluation of indoor daylight levels and corresponding heating and cooling loads. The developed façade structures are intended to adapt real-time, via responding to both results of an undertaken simulation and data-regulation protocols responsible for sensing and processing building performance data. To this extent, a strategy for BIM integrated sustainable design analysis (SDA) has also been deliberated, as a framework

for exploring the integration of building management systems (BMS) into smart building environments (SBEs).

Finally, the research reports on the findings of prototype system development and its testing, allowing continuous evaluation of multiple solutions and presenting an opportunity for further improvement via multi-objective optimisation, which would be very difficult to do, if not impossible, with conventional design methods.

CHAPTER 1: INTRODUCTION

1.1 Background

> *"Architecture is that great living creative spirit which from generation to generation, from age to age, proceeds, persists, creates, according to the nature of man, and his circumstances as they change. That is really architecture."*
>
> – Frank Lloyd Wright

The perpetual nature of change has a fundamental impact on the way the life in our ecosystem has adapted and constantly evolved. Architecture and the built world around us have also over the centuries changed, influenced by climate, traditions, places, religions and different construction styles, and has become an increasingly complex profession, due to an ever-growing demand to fulfil current dynamics of environmental, socio-cultural and economic constraints (Loonen et al., 2013).

As a result, the role of building's envelope changed with the time from an ordinary weather protection role to that which depicts a unique relationship between the surrounding context and the building itself. This relationship is enacted by the forces, perceived as either tangible - the weather conditions such as wind, solar radiation, and rain; or as intangible - the forces occurring from cultural, religious or societal legacy. Vernacular architecture often reveals how those forces can naturally be integrated and harmonised, through a concept of climatic adaptability, where local differences are results of their response to culture, climate, and specific shelter needs (Previtali and Zhai, 2016). Historically, the primary function of the building envelope was that of a shelter, as well as providing an external load-bearing structure for a building. Additionally, it provided a sense of enclosure, privacy and security for the occupants. With the time, it progressively evolved into the form of the exterior decoration and ornamentation, ostensibly to express religious, cultural and social identity, as well as to protect the prosperity, wealth and power. Hence, Egyptian, Greek or Chinese temples and Islamic palaces became very influential and often were a dominant focus in architecture throughout its history (Schittich, 2001).

The type and performance of the building envelope play a significant role in reducing building energy demands. Furthermore, effective shading strategies that prevent overheating of buildings, as well as effective daylight harvesting strategies do lead to a reduction of cooling loads and amount of electricity needed for artificial lighting (Hegger et al., 2008). For example, traditional building envelopes used in Vietnam consisted of layers of vertical, curtain-like wooden constructions decorated with Chinese ornaments, also provide a significant shading and solar radiation protection. Through centuries they have proven themselves to be effective in passive control of occupant thermal comfort, natural ventilation and access to daylight, based merely on rudimental construction techniques and limited local materials available at that time. Obviously, all these were constructed as fixed systems but with a passive climatic mind, protecting occupants from nature and providing basic shelter needs.

> *"No space, architecturally, is a space unless it has natural light."*
>
> – Louis Kahn

Access to daylight is a fundamental aspect in the design of buildings, the purpose of which is to improve indoor environmental quality, maximise visual comfort and provide a connection to outside, improve occupant's health and wellbeing and increase user productivity, whilst reducing the building's overall energy consumption. The emergence of curtain wall construction systems in 19th century and advances in the production of large-scale glazing panels, together with the introduction of aluminium as a construction material in the 1930s, led to a revival of the importance of natural light in architectural design. The 20th-century modernist architecture in particular featured buildings with a vast amount of glazing on their facades. The style was characterised by an emphasis on volume, functional rationality and use of new materials, rejecting ornamentation and embracing minimalism. With the rise of the late modernism and digital age, the façade ornamentation has become once again popular in design (Balik and Allmer, 2016; Gleiniger and Vrachliotis, 2009). Today, the use of cultural patterns and decoration on the façade systems is more frequently encountered, with some architects and designers using advanced parametric design techniques to create those patterns. However, current use of advanced computation in architectural practice is too often focused on aesthetical merits rather than also addressing issues regarding climatic adaptability, which eventually results in a design that fails to meet its primary objectives (Hamdy et al., 2016). Hence, a challenge for architects is to approach façade ornamental design in both culturally meaningful and performance-based way, and study how advanced parametric design could be used to address both aesthetic and functional aspects of a final artefact.

The impact of climate change on population health and livelihoods, and ultimately, the economy, is widely reported and discoursed. The built environment has a significant role to play in reducing global energy consumption and carbon emissions, mainly due to its heating and cooling loads, lighting and appliances demands. Energy security is also becoming an issue which will have an impact on the mix of fuels and energy sources used in buildings, with a move from over-reliance on limited fossil fuel sources to renewable and new technology energy sources becoming inevitable. This will affect total spending for heating and cooling of buildings and approach to the energy security of buildings, leading to reduced energy consumption and impact on the environment. However, the final net energy consumption result is dependent on whether a current increase in population numbers, floor area per capita, and the energy use per m2 can be balanced by a decrease in energy consumption created by sustainable design, renewable energy generation and improvements in building fabrics and services. There is, of course, an economic impact too, as reported in the literature, with estimates of "increase of net global building energy expenditure in the order of 0.1% of global economic output for a 2 °C increase in global mean surface temperature" (Clarke et al., 2018). This increase of building energy expenditure could have a substantial impact on the global economic output and the climate itself, as temperatures increases, and this is just to keep a thermal comfort in buildings as it presently is. However, and possibly more concerning, is the fact that predicted net buildings energy expenditures, due to climate change, are not uniform across the globe. Hence, an expectation that the savings from reduced heating demands can negate additional expenditure resulting from increased cooling demands is not likely to happen. The increase in expenditure is expected to be at its largest in low latitude countries where present-day heating demands are already very low, whilst future demands for space cooling are anticipated to increase considerably, given the direction of global warming and climate change. Incidentally, this is where most of developing countries and vulnerable regions are located, and this is where the impact of climate change is at its most evident. Economically, this is also where the ratio of income growth versus increased building energy expenditure is at its lowest (Clarke et al., 2018).

Hence, the concept of climatic adaptability has to be constantly revisited, now and in the future, examining as to what is that we need to adapt to, what is it that we need to adapt, and where and when we need to adapt (Dave et al., 2018). The idea of building adaptation and adaptability is not novel, as evidenced in the literature review, with phrases such as "Climate Adaptive Buildings", "Design for Adaptability", "Adaptable House/Housing", "Adaptive Architecture" often encountered. Such buildings should be capable of responding not only to short-term changes in weather and the seasons but also to those likely to follow over decades to come (Ceranic et al., 2018). Passive approaches, such as solar shading, daylight and natural ventilation, use of thermal mass and taking advantage of natural cooling are recorded through history as effective means of adapting buildings to different climates, mostly by virtue of reducing heating and cooling demands whilst providing acceptable levels of thermal comfort within the building. Recently, those passive vernacular approaches have enjoyed a revival in contemporary sustainable design, is often referred to as "sustainable and economical alternatives to current conventional techniques" (Samuel et al., 2013). However, Meir and Roaf (2005) argued that "assuming an inherent climatic suitability or superiority of materials and forms in vernacular buildings may be misleading", considering many other reasons that would have an impact on shelter construction and typologies at the time, not least the availability of local materials, their structural and constructional capabilities, as well as cultural, political and economic factors. In truth, it is likely that climatic adaptability was considered being of lesser significance. Hence, any design decisions based on vernacular designs of the past, without a true understanding of its limitations, could lead to the perpetuation of poor practice, sustainably, environmentally and health-wise (Cicelsky and Meir, 2014).

Computational design has in recent years played an increasingly important role in expanding our understanding of design creativity by providing a digital playground for expressing different models of creative expression, as well as providing interactive environments for enhancing human creativity (Maher, 2012). In its broader sense, computational design encompasses generative design, parametric design and algorithmic design, all of which have the potential to effectively deal with an inherent complexity in the design process (Scheurer, 2010). Cognitive thinking within computational environments can also lead to different approaches in creative exploration, for example how we generate alternatives (Maher and Tang, 2003), how we manage constraints (Aish and Woodbury, 2005), or how we interact with digital models (Gül and Maher, 2009; Kim and Maher, 2005). Moreover, large scale people participation through either social networking or online virtual environments can bring another, often unexpected dimension, to a resolution of complex problems (Maher et al., 2011), where human creativity can be augmented or enhanced in a unique way. The creative diversity that can be realised in such crowdsourcing experiments has led to an emergence of research in large-scale social creativity and digital innovation.

Such augmented creativity, however, hardly achieves contributory significance without a meaningful purpose of pattern generation. In this study, the Vietnam and traditional Vietnamese patterns, symbols and motifs are central to its research, being founded upon the Vietnam and its cultural heritage rather than simply using Vietnamese cities as case studies. For those reasons, the research combines human creativity and computational design by utilising both of the above for the purpose of creating a new generation of Vietnamese cultural patterns in the form of sustainable solar shading devices, adaptable to the climate of Vietnam.

1.2 Global Warming and Climate Change - Key Challenges

In the past few decades, we have seen a growing concern regarding climate change, in terms of its impact on ecosystems and humans. The year 2016 has been declared as the hottest year on record, with an average global temperature of 0.94 °C above the 20th century average, the highest rise since 1850 (Met Office, 2018). Relative to 1850-1900, if emissions continue to follow current trends, it is expected that the global surface temperature change will exceed 2°C over the period 2081–2100, as illustrated in Figure 1.1 (IPCC, 2018).

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Figure 1.1 Observed global temperature change and modelled responses to stylised anthropogenic emission and forcing pathways. (Source: IPCC Special Report 2018 on the impacts of global warming of 1.5°C).

The emissions of anthropogenic greenhouse gas (GHG) have been rising steadily since the pre-industrial era, reaching their maximum levels at present, influenced by economic growth, developments in fossil fuel-based technologies, and growth in population. This has led to an increase in atmospheric concentrations of carbon dioxide, methane and nitrous oxide, currently at their highest level in the past 800,000 years (NOAA, 2018). Approximately half of the anthropogenic CO_2 emissions in the past 270 years have occurred just in the last 40 years. Their negative impact, compounded by other man-made causes, has been considered being the main cause of global warming since the mid-20th century (IPCC, 2014). Reducing the impact of climate change, therefore, requires significant and continual reductions in GHG emissions that, together with developments in sustainable design and new green technologies, can reduce the risks associated with global warming.

The surface temperature is predicted to rise in this century under all assessed emission scenarios (see Figure 1.2). The acidification and warm-up of the oceans will continue, with global mean sea level continuing to rise and with some of the most severe impacts of climate change predicted to happen in the tropical and subtropical regions. It is very likely that heat waves will occur with a higher frequency and over longer periods. At the same time, occasional cold winter extremes will be also be observed (IPCC, 2018).

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Figure 1.2 Change in average surface temperature (a) and average precipitation change in (b) based RCP2.6 (left) and RCP8.5 (right) multi-modal prediction scenarios. (Source: IPCC 2018).

The worldwide contribution from the built environment and construction industry to global warming and climate change is substantial, and it continues to grow. According to World Green Building Council (WGBC) United Nations Global Status Report 2017, it accounts for 36% of global final energy use and 39% of energy-related carbon dioxide (CO_2) emissions (see Figure 1.16).

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Figure 1.3 Up: Share of global final energy consumption by sector, 2015. Down: Share of global energy-related CO2 emissions by sector, 2015. Source: Source: derived with IEA (2017), World Energy Statistics and Balances, IEA/OECD, Paris, www.iea.org/statistics.

The improvements in energy efficiency made in recent years did not keep up with the rise in additional floor area worldwide, leading to an overall increase in buildings final energy demand, by 5 EJ from 2010 to 2016. There is now an urgent need to slow down a rapid growth of carbon-intense and energy inefficient building developments, especially in developing countries (see Figure 1.4). For example, the issue of overheating in buildings is becoming more common around the world, given the rise of global temperatures. The improvement in residential cooling equipment performance from typical (a co-efficient of performance COP of 3) to best accessible technologies, whose efficiencies can be as high as COP of 6, could generate energy savings of 3.5 EJ by 2025. To put this in context, 3.5 EJ of energy is slightly less than total electricity use in India in 2015 (WGBC, 2017).

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Figure 1.4 Building Sector CO2 Emissions per unit of Final Energy Consumption, 2015 (IEA, 2017).

The increase in energy demand stems from rising population numbers, demand for additional floor area and intense buildings sector activity (see Figure 1.5). Building growth is expected to be particularly rapid in Asia and Africa, and evidence of this can be easily observed at the present time. For instance, the floor area in India is expected to double by 2035 (IPCC, 2018).

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Figure 1.5 Building floor area additions by key regions (IEA, 2017).

Additionally, population growth, migration to big cities, changes in house sizes, increase in wealth and changes in lifestyle all contribute to the expansion in building energy consumption.

The amount of new construction that is taking place in developing countries represents both significant risk and opportunity, from a mitigation perspective. Still, despite the significant growth of economies in developing countries and rapid improvements in living conditions, the developed world is still responsible for a disproportionate amount of energy consumption per capita, as illustrated in Figure 1.6 below.

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Figure 1.6 Annual per capita energy use of residential and commercial buildings for 11 world regions, in 1990 and 2010. Data from IEA (2013).

Worldwide, space heating covers approx. third of total building energy consumption (see Figure 1.7). Commercial heating and cooling energy use are expected to strongly grow until the middle of the century, with 84% projected increase by 2050, compared to 2010 (IEA, 2013).

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Figure 1.7 Global building final energy consumption by end-use in 2010. Source: IEA (2013).

Although the progress towards sustainable buildings and construction is advancing, improvements are still not keeping up with a growing buildings sector and rising demands (see Figure 1.8). The energy intensity per square meter (m^2) of the global buildings sector needs to improve on average by 30% by 2030 (compared to 2015), to meet targets set by Paris Agreement (UNFCCC, 2015).

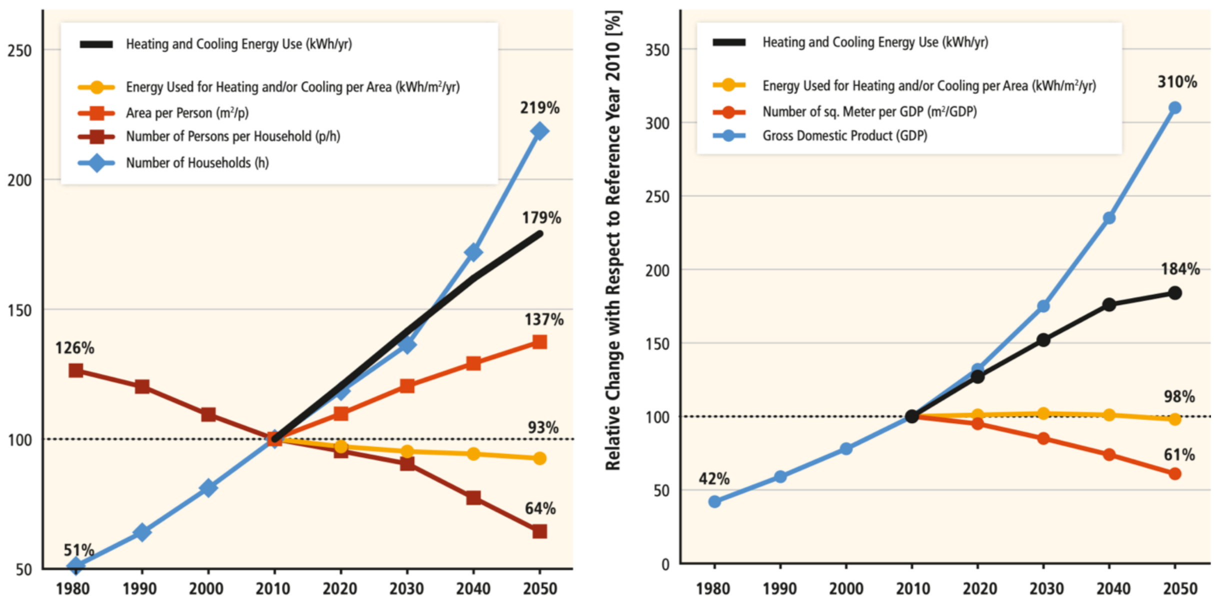

Figure 1.8 Trends in various drivers for global heating and cooling energy consumption in residential (left) and commercial buildings (right). Data adapted from Ürge-Vorsatz et al. (2015) with projection data (2010 – 2050).

Rapid economic development and urbanisation are driving intense building activities in developing countries (Li and Colombier, 2009). Whilst the intensity of new build construction in those countries is remarkable, they still have a long way to go to satisfy growing population needs for basic housing and reliable energy supply, that is yet to be realised. In order to avoid being locked in the carbon-intensive activities for many decades to come, an increase in energy demand in these countries needs to be counterbalanced by energy-saving solutions in urban and building design, as well as renewable energy generation and management, and sustainable lifestyles (Prinz and Nussbaumer, 2014). Current advances in technology and design practices, coupled with behavioural changes, can achieve significant reductions in energy demands, of both new build and existing building stock. These reductions are achievable regardless of climate conditions. Published work reports that good sustainable design can attain thermal comfort without mechanical cooling for majority of the year, in hot and humid regions such as Shanghai, China (Lin and Chuah, 2011; Zhang et al., 2016), Brazil (Cândido et al., 2011), and the tropics (Lenoir and Svenning, 2013). Furthermore, it does not need to be more expensive. Current IPCC studies show that close to half of reductions in emissions cited for 2010 and 2020 are achievable at "net negative" costs, i.e. the value of saved energy is greater than the total of capital expenditure and operating/maintenance costs (IPCC, 2018).

1.3 Rationale and Justification of the Research

1.3.1 Buildings and Culture

At the end of the 20th century, there was "*a shift of historic proportions taking place and architecture is the premiere symbol of that transformation…the Chinese, as well as many other Asians, tend to want buildings as tall as possible and in a pretentiously Modern style*" (Progressive Architecture 1995: 44, 66). According to New York architect Kohn Pederson Fox, the reason was to "*catch up with the West*". Asia did no longer wanted to be seen as the Third World countries. Buildings in China and India were chosen primarily for their impact on the city's skyline. Energy efficiency and architectural identity were at that time not considered. Not long after that, the trend has expanded towards many other countries and cities in Asia, developed or undeveloped, urban or semi-urban. Certainly, for this trend to enter Vietnam, a country close to China and Japan, was just a matter of time. One can barely recognise, nowadays, what city it is, in the photo that he's looking at. From afar, Saigon these days looks like Bangkok, which looks similar to Hong Kong, and so on.

The 20th century marked spectacular developments in building design and technology, able to achieve indoor thermal comfort requirements regardless of external climate conditions. Together with advancements in construction technology and materials, they created a new style of architectural expression and aesthetics, often referred to as the “International Style”, which was recognisable by glass dominated geometric forms bounded by flattening, unornamented facades. A quest for mechanically controlled indoor climate led to a spread of similar style in architecture around the world, whereby an office building in London or in New York could look more or less identical to one in Tokyo or Singapore, regardless of differences in local climatic conditions or cultural context. At later stages of 20th century, this relentless technological progress raised concerns amongst critics about the loss of identity and a key function of buildings, as the building facade lost its role of a climatically adaptable interface between an indoor and outdoor conditions. Neither variation in climate nor the cultural identity of a city was truly considered.

1.3.2 Vietnam’s Overgrowing Population and Urbanisation and its Increasing Demand for Constructions

Similar to many other countries in South Asia, Latin America and Africa, Vietnam has experienced fast urbanisation in many of its regions (Beall and Fox, 2009).

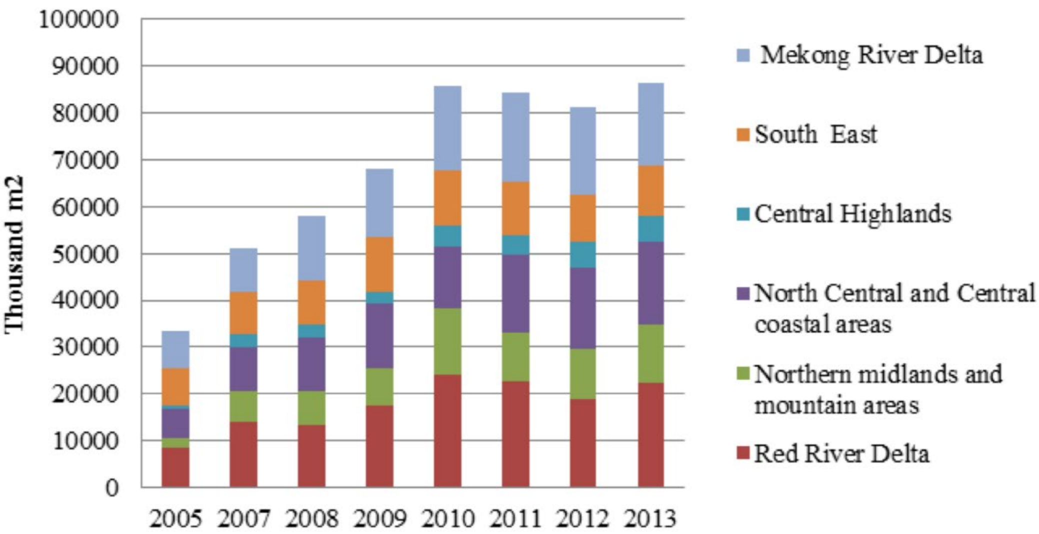

Figure 1.9 Floor Area construction in different regions of Vietnam from 2005 to 2013.

Currently, Vietnam population is 90.7 million, with growth predictions to 108.7 million by 2049. It already has 58.8% of the population living in urban areas, which is driving an increase in demand for construction, both residential and commercial (Nguyen and Gray, 2016). Indeed, from 2005 to 2013, Vietnam construction statistics show an increase of 140% in the average of housing floor areas, as illustrated in Figure 1.9 (General Statistics Office Of Vietnam, 2016).

1.3.3 Energy supply insecurity

Rapid urbanisation, growth of economy, industrialisation, and rising population are key causes of a significant increase in Vietnam's energy demand. The statistics report an annual increase of 9.3% in energy demand between 1990 and 2007, with a further increase of 5.5% predicted annually by 2025. Current energy production is primarily based on fossil fuels, i.e. coal, oil, natural gas (Duc Luong, 2015). This heavy dependence on fossil fuels has led to a carbonisation of energy supply in Vietnam on the rate which is faster than the world average, including China and most of the newly industrialised countries (see the rate of carbon intensity in Figure 1.10-d). It has also made Vietnam energy supply strategy more vulnerable in terms of its over-reliance on a source of fuel which is fast depleting.

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Figure 1.10 CO_2 emissions per capita and energy factors of Vietnam, China, and newly industrialised countries (NICs) (Zimmer et al., 2015).

The reserves of oil and gas are reducing at a rapid rate and will not be able to provide for energy production in the next 25 years (Do and Sharma, 2011). Moreover, due to a rain-fall dependence of hydro energy production, and reduction in generation capacity, the national grid experiences regular power shortages in the summer. Figure 1.11 shows that Vietnam will, unsurprisingly, become a net importer of energy within a decade, as its energy demand exceeds the supply. Hence, the government should promote energy efficiency, support market-based energy pricing and a long-term policy of energy efficiency (Nguyen, 2008).

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Figure 1.11 CO_2 emissions per capita and energy factors of Vietnam, China, and newly industrialised countries (NICs), Source: Zimmer et al., 2015.

1.3.4 Environmental Harm and Negative Impacts of Climate Change

Vietnam's long coastal line and low-lying Mekong delta with dense population make it particularly vulnerable to climate change (Neil Adger, 1999). International Panel on Climate Change (IPCC) forecasts that Vietnam will be *"one of the five nations most severely impacted by rising sea-levels and one of six countries in Pacific-Rim region most vulnerable to climate change"*. The pattern of more frequent and severe typhoons during the monsoon season is already observed, with increased occurrence of unpredictable amounts of rainfall and droughts in different locations and seasons (Lohmann and Lechtenfeld, 2015; Rutten et al., 2014). Carew-Reid (2007) predict that scenario of a one-meter sea-level rise by 2100 could devastate estimated 4.4% of Vietnam's territory and affect up to 6 million people. Under the IPCC highest emission pathway (see Figure 1.12), it is estimated that the average temperature could rise between 3.4°C - 3.7°C, with sea levels increasing up to 95cm, leading to a loss of 22 million homes and 45% of agricultural land in the Mekong Delta.

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Figure 1.12 Projected Vietnam's average temperature in the 21st century under different emissions scenarios. Source: AR5 Synthesis Report: Climate Change (IPCC, 2014).

Industrialisation, urbanisation and excessive consumption of natural resources have, and continue to have a direct impact on air pollution and increase in CO_2 emission (Al-Mulali et al., 2015; Lee et al., 2013). This is particularly concerning for agriculture and food security, which plays the most important role in the Vietnamese economy, making up over 21% of its GDP. Since its economic strength lies in coastal zones and the nearby lowlands, which are rich in natural resources, climate change could greatly damage Vietnam's wealth and standard of living (Hoang, 2011).

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Figure 1.13 Days with the heat index above 35 °C (IPCC, 2014).

This uncertainty adds to the reasons why people from rural areas migrate towards urban environments and cities, seeking employment and educational opportunities in order to diversify their income and reduce dependency on the agriculture, urban phenomena often referred to as rural-urban migration (Nguyen et al., 2015). This is creating a greater demand for buildings and energy that is required for construction and operational activities. On the other side, higher temperatures are leading to greater needs for cooling in buildings (see Figure 1.13), as the number of degree cooling days increases and people lifestyle changes lead to spending an increasing amount of time indoors.

1.3.5 Vietnamese Buildings and Climate Change

Since a building provides an interface between outdoor climate and indoor environment, the building energy consumption, particularly the energy used for air-conditioning, is directly related to the outdoor weather, which is changing under the impact of global warming. Consequently, the frequency of overheating days is increasing, and so is the demand for cooling of buildings. More extreme weather conditions predicted in future will limit the ability to use natural ventilation in buildings, whilst currently, effective passive design strategies will become increasingly less able to deliver acceptable indoor thermal comfort levels (Bank, 2009). In addition, fluctuations in annual maximum and minimum temperatures are expected to become more extreme and volatile, with negative impacts on human health and livelihoods becoming more intense. Given the predictions above, these changes will lead to a substantial increase in the use of energy for cooling in Vietnamese buildings. Hence, the use of passive design strategies, such as solar shading, will become even more critical in helping to prevent excessive overheating and significantly reducing annual cooling load demands in buildings in Vietnam.

1.3.6 The Green Building Movement in Vietnam

The green building movement started in the 1970s in Europe and US, initially influenced by the oil embargo enforced by Organization of Petroleum Exporting Countries (OPEC), and thereafter developed as a response to impacts of global warming on the climate change. Green building design (GB) was then described by US Green Building Council (2007) as the "*practice of creating and using healthier and more resource-efficient models of construction, renovation, operation, maintenance and demolition*".

In Southeast Asia, six countries formed Green Building Councils and adopted their own rating systems. These were Indonesia with Green Ship, Malaysia with Green Building Index, Philippines with Building for Ecologically Responsive Design Excellence, Singapore with Green Mark and Vietnam with LOTUS (Reed and Krajinovic-Bilos, 2013; Wilkinson et al., 2011). The introduction of the rating system has led to an increase in the number of buildings receiving "green" certification. However, recent surveys point out that in the region, sustainable design as a concept is still relatively new and remains largely unexplored. In particular, a number of key stakeholders in the construction industry are not even aware of the GB concepts (Shafii and Othman, 2015).

Vietnam Green Building Council (VGBC) was established in 2007, leading the green building development in the country and receiving increased attention from both the government and the industry. It played a key role in engaging experts in construction in the development of LOTUS, a Vietnamese GB certification, founded mainly on concepts of USA's LEED standard. In comparison to LEED, LOTUS has a lower cost of implementation and is more locally applicable, but LEED is certainly more recognised worldwide (SOLIDANCE, 2013).

However, despite above efforts, the adoption of sustainable building design in Vietnam is still criticised as being too slow, predominantly due to a lack of governmental support and lack of recognition of its benefits by the market and economy, which is unlikely to change anytime soon. It is now up to a new generation of Vietnamese people, professionals, scientists and academics to reassert positive pressure, through their behaviour, research and everyday practice, and in doing so help to mitigate potentially cataclysmic impacts of the climate change in this country.

1.4 Research Aim and Objectives

1.4.1 Aim

The proposed study aims to research, develop and critically evaluate novel parametric generative design tools and strategies for innovative and responsive kinetic facade shading systems, aimed at contemporary design in Vietnam. They will be extracted from theoretical research and implemented using generative design approaches based on the conjectural constructs of shape grammar, building information modelling (BIM) integration, building simulation and system optimisation.

1.4.2 Objectives

To achieve this aim, the following objectives have been identified:

1. To undertake an in-depth literature review and critically explore current approaches to the sustainable kinetic design of façade shading systems.
2. To analyse and critically resolve novel theoretical approaches to adaptive kinetic pattern design in relation to parametric generative design methods in architecture.
3. To develop parametric strategies and propose original shape grammar languages for the design of kinetic façade shading systems, inspired by the research into origins and history of traditional patterns, motifs and ornaments in Vietnam.
4. To develop and critically evaluate, via extensive thermodynamic simulations, a novel prototype framework for adaptive and responsive kinetic shading systems.
5. To formulate a strategy for BIM integrated sustainable design analysis (SDA) and optimisation of kinetic façade shading systems, as a conceptual framework for exploring the integration of building management systems (BMS) into smart building environments (SBEs).

1.5 Research Design in Brief

To accomplish research objectives, an author has conducted a wide range of interdisciplinary studies. These included investigations within the domains of shape grammar based formal designs, the art of Vietnamese cultural patterns and ornaments, adaptive solar shading kinetic facade systems and the research associated with the sub-topics of generative computational design and optimisation. Figure 1.16 illustrates an overall relationship between the aforementioned fields in the form of a complex network, represented by the multiples of interconnected topics and their relationships. It is based on bibliometric analysis of the scientific contribution of authors, sourced from an undertaken literature survey.

It became clear at the early stages of the research that in order to alter such complexity, the research will require an adaptive and innovative way of thinking. This research philosophical position is grounded on Dewey's Pragmatism Philosophy (Dewey, 1938; Prall and Dewey, 1935); and research methodology was then developed using the framework for Systems Development proposed by Nunamaker et al. (1990). This development is presented in detail in Chapter 2, with the main framework elaborated in Chapter 6.

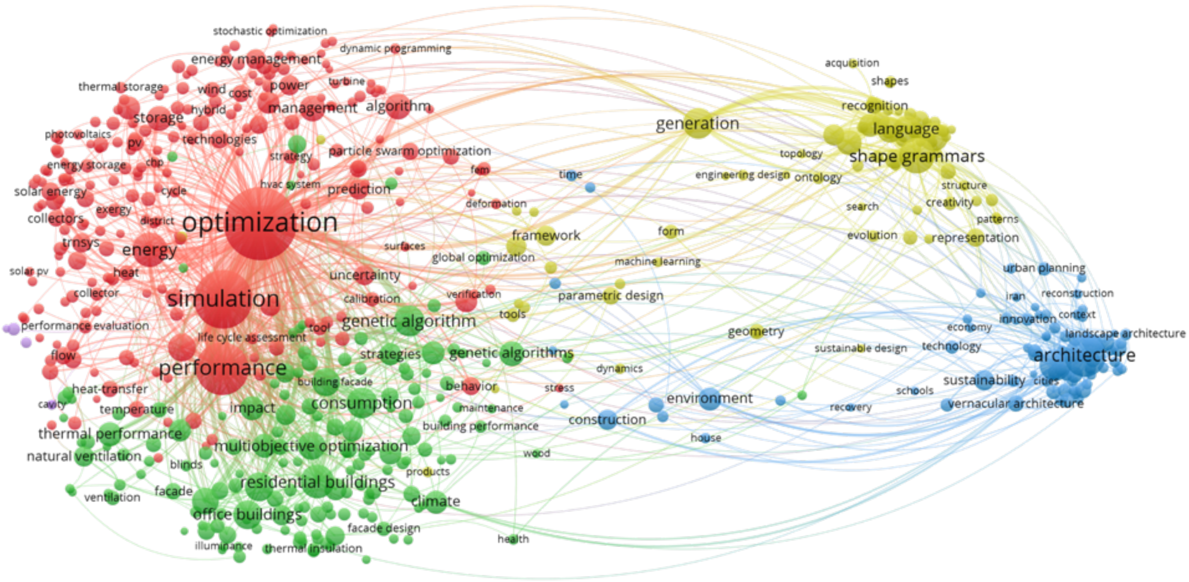

Figure 1.14 The Big Picture – Research Approach, Interdisciplinarity and Interconnectivity. (Source: Author).

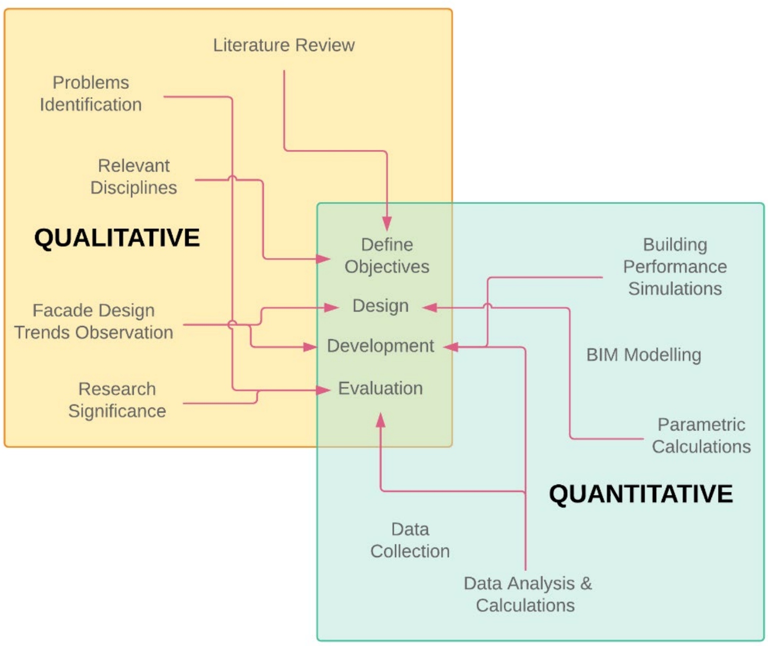

Figure 1.15 Overview of the qualitative and quantitative approach. (Source: Author).

In the context of this study, both quantitative and qualitative research methods have been used, implying a mixed methodology approach of “research through design” (Downton, 2003). This was considered a suitable method for problems without a single solution and with changing requirements, where the research explores theoretical models through applied, design-based research investigation. This indeed is more natural to a process of design, conceived as a realisation of a concept through imagining and planning the creation of an artefact, based on the synthesis of knowledge, creative expression and experience (see Figure 1.15).

Qualitative research is commonly perceived as allied with discovery, narratives, understanding and personal perceptions, in which the researcher preconceptions and philosophies are part of the research process. Quantitative research, on the other hand, provides means of functional and often numerical quantification of those preconceptions, through an objective and methodical results analysis, in the form that works within a design science paradigm. Quantitative research is therefore associated with impartial logic, calculations or measurements, ensuring that the researcher preconceptions withstand the rigour of scientific examination (Sanghera, 2007).

1.6 Research Originality and Contributions

To the best of knowledge of the researcher, which was greatly reinforced by extensive literature review, engagement with other researchers in the field, and peer reviews from published international conference proceedings and submitted journal publications, this research proposes a novel approach for generative computational design of kinetic facade shading systems, and hence originally contributes to the existing body of the knowledge in the field.

This has been achieved through research, conception, development and generation of original sets of shape grammar rules and languages, inspired by a detailed investigation into origins and history of traditional Vietnamese patterns and ornaments. They have been incorporated within a BIM integrated framework for the generative design of climatically adaptive kinetic facade shading systems, developed in this research. The approach represents a unique synthesis between multiple matters in the contemporary design of building façade systems, namely:

1. Decoding the origins, history and language of vernacular Vietnamese cultural patterns, motifs and ornaments and creation of novel rule-based generative designs, validated through simulation and optimisation of daylight levels and building energy performance.

2. Creation of original parametric design strategies which were extracted from theoretical research and developed using generative computational design tools, used for the creation of adaptive and responsive kinetic systems for Vietnamese contemporary façade shading design.

3. Development of a novel conceptual framework for BIM integrated sustainable design analysis (SDA), and optimisation of kinetic façade shading systems has been formulated, including the integration of building management systems (BMS) into smart building environments (SBEs).

1.7 Thesis Structure

The structure of this thesis is explicit and follows a chronological progression of the research journey. It consists of 9 Chapters, as illustrated in Figure 1.16.

Chapter 1: Introduction

This chapter introduces the topic of the proposed research and offers a background for the study. It clarifies why this research was undertaken and how this research is significant to the field of kinetic facade shading systems design. Research aim and objectives, a justification for the research, originality and contribution are discussed.

Chapter 2: Research Methodology

Following the introduction to the research, this chapter explains the methodology behind the research, depicting both primary and secondary sources. It includes a description of the process of the research and rationale for research design and methods selection, system design and development, applied design simulation techniques and system validation.

Chapter 3: Origins and Depiction of Vietnamese Patterns and Ornaments

This Chapter presents a theoretical and historical overview of Vietnamese art and architecture, in particular exploring the origins and history of Vietnamese decorative patterns, motifs and ornaments. It further decodes a secret language behind, setting the scene for the creation and development of shape grammar. A discourse of traditional and contemporary trends on facades and shading devices used in Vietnam is also provided.

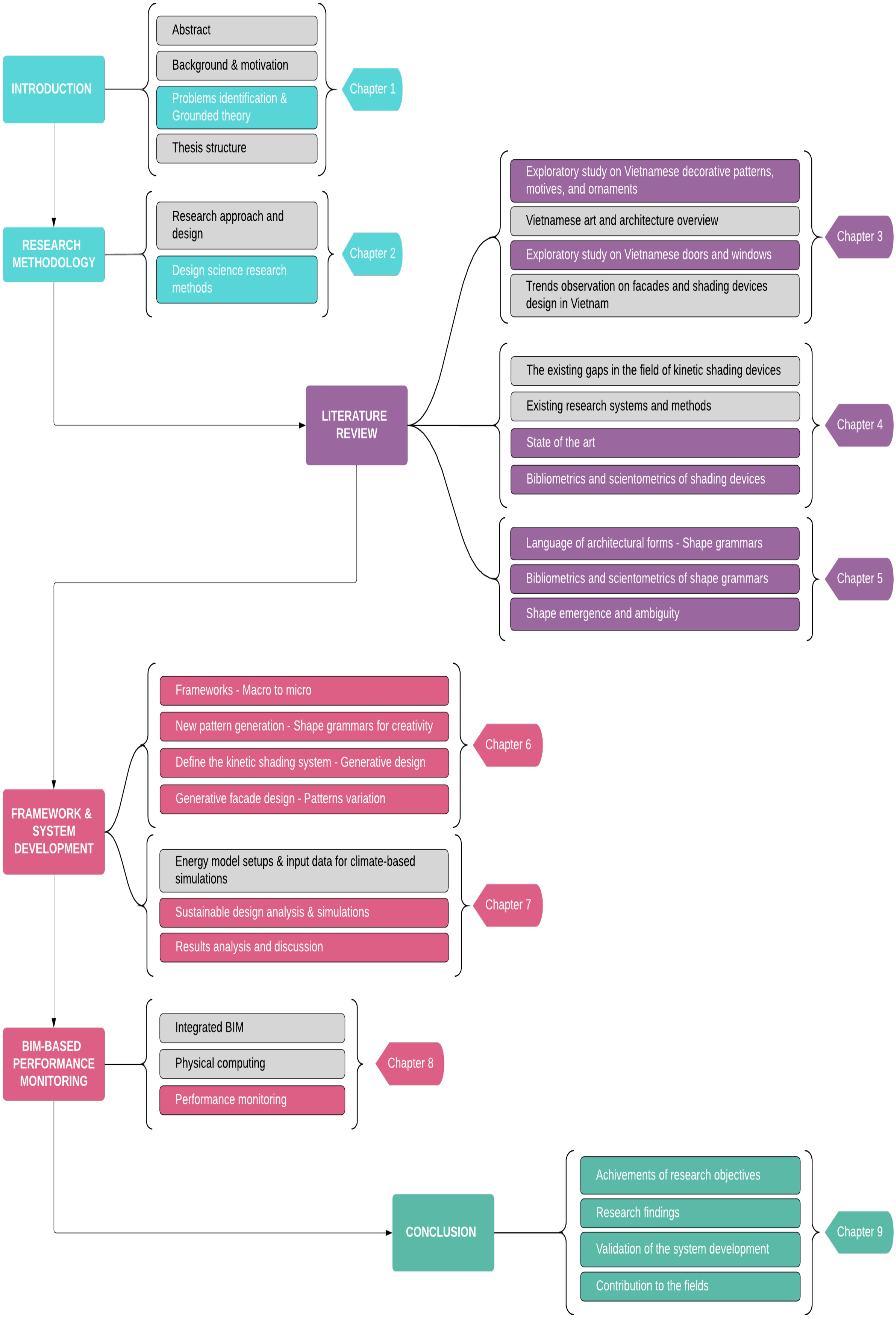

Figure 1.16. Structure of the thesis. (Source: Author).

Chapter 4: Solar Shading Devices

Building upon knowledge gained from the literature review, this Chapter explores state of the art in kinetic shading systems design, giving a detailed overview of their approach to climatically adaptive design, technologies, components and materials used in the design. It provides bibliometrics and scientometrics relevant to this field of the research and concludes upon the existing gaps in the research.

Chapter 5: Language of Architectural Forms – Shape Grammars

This chapter builds on a theoretical study undertaken in Chapter 3 by reviewing the language of architectural forms, namely shape grammar, its history, types, rules of composition, shape emergence and ambiguity. It also provides bibliometrics and scientometrics relevant to this field of the research and reflects upon the use of shape grammar in this research.

Chapter 6: KiSS - Design Framework for Vietnamese Adaptive Shading Device Systems

Chapter 6 presents the development of a novel design framework, based on the parametric design strategies extracted from theoretical research presented in Chapters above, and developed for the creation of climatically adaptive kinetic shading systems for Vietnamese contemporary facade design. The key concepts, creation of rules and language of shape grammar, patterns variation, and new pattern generation using computational design are elaborated.

Chapter 7: System Analysis and Validation

This Chapter presents energy models setup, input data selection and climate-based simulation and analysis in order to critically validate, via extensive thermodynamic simulations, a novel prototype framework for adaptive and responsive kinetic shading systems. Results are analysed and discussed, and approach for their reintegration within BIM framework is explained. Finally, they are validated and benchmarked against the research published in the field.

Chapter 8: BIM Integrated Real-Time Performance Monitoring and Evaluation

Chapter 8 present a novel conceptual framework for BIM integrated sustainable design analysis (SDA) and optimisation, including the integration of building management systems (BMS) into smart building environments (SBEs). Although developed only to the “proof of concept” level, it is an important part of this research in terms of exploring integration within the overall BIM framework, hence providing a viable approach to real-time performance monitoring and evaluation during the whole lifecycle of a building asset.

Chapter 9: Conclusions and Recommendations
This chapter reflects on the achievement of research objectives, summaries research findings, concludes upon the validation of the developed system and recommends several directions for future research.

1.8 Chapter Summary

The opening Chapter explains the rationale for use of solar shading devices in Vietnam, discoursing on the need to tackle the interrelated encounters, from significant demand for new build construction to a forecasted shortage of energy supply and projected damage caused by the climate change. In effect, the research investigates the vernacular architecture's environmental responsiveness through the use of traditional patterns; and proposes a multi-purpose solar shading system of environmental, cultural, and technological dimensional values. It details a creative effort to connect the poetics of patterns and ornaments with functional performance of solar shading devices. Also, this introductory Chapter shows a determination to approach mixed-method research by a combination of design theory and creative practice concepts. Importantly, the original contribution of the research is highlighted via theoretical shape grammar's pattern generation and its computational practical applications. Finally, the Chapter provides reader with an abstract for the structure and content of the Thesis.

CHAPTER 2: RESEARCH METHODOLOGY

"Scientists try to identify the components of existing structures; designers try to shape the components of new structures."

- Alexander, 1964.

2.1 Introduction

As stated in Chapter 1, the aim of this study is to research, develop and critically evaluate novel parametric generative design tools and strategies for innovative and responsive kinetic facade shading systems (KiSS), aimed at contemporary design in Vietnam. This chapter deliberates on the methodological approach and its theoretical discourse, as applied to this research. Following on from this, a methodology for KiSS framework and system development is presented.

2.2 Philosophical Standpoint

The research approach is a philosophical view, a mind-set of the researcher that is guided by the key principles, core scientific beliefs and values, reflecting upon how a researcher undertakes and logically conducts research. The two key philosophical research standpoints often considered in built environment investigations are ontology and epistemology (Bryman, 2008). Ontology questions the nature of being, exploring the meaning of reality through objectivism and constructivism. Objectivism represents a more pragmatic view of reality that is absolute and waiting to be discovered, whereas constructivism deliberates a more active role of reality which is relative and socially constructed.

Epistemology, on the other hand, is the theory of knowledge, its methods, validity and how knowledge about reality is gained (Krauss, 2005). It adopts two key approaches, positivism and interpretivism. The positivism uses deductive reasoning through the application of quantitative methodologies whilst interpretivism uses inductive reasoning through the application of qualitative methods. Thus, objectivism works well with positivism, whilst constructivism works better with interpretivism.

This research deals with multiple distinct fields, which together can exhibit conflicting ontological and epistemological approaches and methods. Firstly, there have always been debates how architecture, architectural design and design, in general, relates to creative arts on one side and science and engineering on the other. Matters related to aesthetics, (aesthetic) experience and creativity have not yet gained clear agreed definitions from academics. The latter, in many cases, lead to terms like '*artistic creativity'* and '*productive, innovative creativity'*. Despite being commonly used in design theories, they are 'controversial and ambiguous' terms in literature and researchers seemingly avoid defining these terms in their works.

In fact, Schön (1983) promoted a type of research distinctive to other known methodologies, the terms he defined as '*reflective research'*. According to Buchanan and Margolin (1995; 1996), the Schon's 'reflection' ideology, which is supported in this research, helps verify the discrepancies among design research, research in design and design theory. Also, Schön and Buchanan, two of the design theorists, have merged Dewey's pragmatist theory with theoretical investigations in design. Indeed, there has been growing attention amid architectural and design theoreticians in pragmatist philosophy and notions of objectivism and positivism, started since the beginning of 20th century, seeking to create a strong 'ground' for architectural theory.

Johnson and Gray (2010) and Onwuegbuzie and Leech (2005) see pragmatism as a suitable paradigm for conducting mixed-methods research. Teddlie and Tashakkori (2009) argue that the established literature in mixed methods research suggests pragmatism as the "best paradigm" for this type of research through simultaneously encouraging positivism and epistemological pluralism. This can be interpreted that, unlike the accurate objectivist methodologies, the pragmatist philosophy applied in mixed methods research offers flexibility for selections of research methods (Creswell and Clark, 2010). Those perspectives are explained by Dewey – an American philosopher and educator, in his books *Logic: The theory of inquiry* (1938) and *Art as experience* (1935) as pragmatist philosophy.

Dewey's pragmatist philosophy is a universal concept of creative and investigative developments in which real-world reasoning, imaginative creation and scientific research are all seen to have the same form of systematic inquiry – i.e. outlining questions, seeking solutions, analysing and evaluating the findings. This does not mean that Dewey ignores the precision of scientific methods; rather he acknowledges rationality and reasoning as devices for the foundation of understanding. Indeed, through the adaptable collaboration between human and unclear, complicated and challenging circumstances, he can see continuousness and diverse natures of truth as correlated. In this context, Dewey's inquiry is understood as follows:

- An overall narrative of creative development.

- Guidance on how to implement design research.
- An attitude towards the journey of design.

Therefore, the pragmatism paradigm promotes a research approach which is able to comprise both the objectivist and constructivist paradigms accompanied by research subjects that define the choice of quantitative, qualitative and mixed methods.

2.3 A Multi-Methodological Approach

As mentioned in the research overview, this research concerns with aim to achieve a multiple-objective paradigm for its contribution to the development of a grammar-based and performance-based kinetic shading design system that does not yet exist. In fact, the research subjects in the fields of geometric pattern generation, building façade architecture and computational design are typically intricate and contextually positioned. Also, culture and cultural value are important matters in social science but are undefined terms in natural science, especially in design-related research, for example, empirical studies and practical projects. In the context of sustainable architecture design, they are not considered as influential subjects. However, traditional patterns, which are results of cultural inspiration, are part of the key objectives of this research.

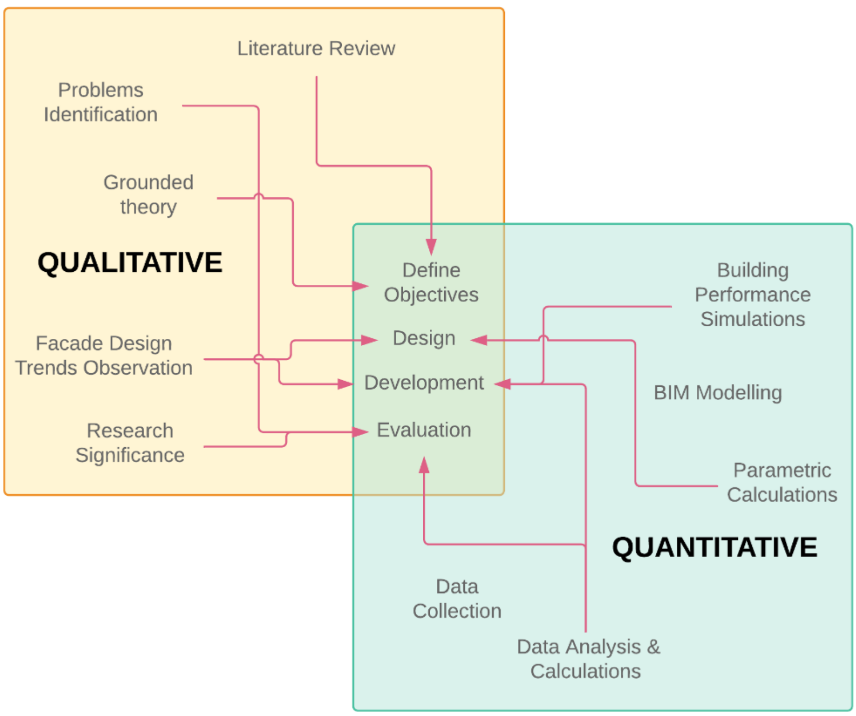

Figure 2.1 Overview of the qualitative and quantitative approach. (Source: Author).

In particular, methodological pluralism denotes the way in which a number of methods are used in the same part of the research, comprises searching for meaning in a range of sources of information. It denotes to the belief that there is not a precise research method that is intrinsically the best or superior to others (Barker and Pistrang, 2005), instead, distinctive methods can be appropriate for a diverse set of purposes (Morgan, 1980; Polkinghorne, 1984). This enables the triangulation where both qualitative information and quantitative data are constructed to elaborate research rationality and reliability (Teddlie and Tashakkori, 2009).

The emergence of a vast mixture of methods occurs in both the natural and social sciences. Its mainstream is labelled as a descriptive and prescriptive approach with both placing emphases on defining the real-world. This research requires both since it fits comfortably between two sides; one has descriptive characteristics of cultural and architectural importance, aiming at development of a grammar-based evolutionary patterns; and the other belongs to building simulation and computational design, which classified by Simon (1981) and Cross (1993, 2000) as principally prescriptive disciplines, which focus mainly on the technical modelling and evaluation of the computational system.

A research area that contains some suitable methods for this research can be defined as Information Systems (IS). As defined by Keen (1987), information systems research is "*the effective design, delivery, use and impact of information technologies in organisations and society*". Noticeably, although a design scheme may not belong to an area generally agreed to be information systems, a vast number of research frameworks established in this field, have been proved to be suitable to this category of research (Hevner et al., 2004; Peffers et al., 2007). Evidently, according to Glass (1999) and Winograd (1996), the significance of design is widely documented in the information systems literature.

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Figure 2.2 A Multimethodological approach to Information System Research, adapted from Nunamaker et al. (1990).

Nunamaker et al. (1990) proposed a multi-methodological approach (see Figure 2.2), which introduced the integration of system development into information systems research process. The multi-methodological approach involves building theories, systems development, experimentation, and observations. To date, the systems development has been verified to be an imposing research methodology for conducting research in design.

2.4 Literature Review

A review of literature covered key components for the development of a framework for innovative and responsive kinetic facade shading systems (KiSS), aimed at contemporary design in Vietnam. The overview of the developed methods for promoting this research confirms a gap in the knowledge of BIM integrated climate adaptable kinetic facade shading systems. The key focus of the literature survey was on:

1) Building adaptation and adaptability
2) Origins and Depiction of Vietnamese Patterns and Motifs
3) Kinetic Solar Shading Devices
4) Language of Architectural Forms – Shape Grammars
5) Adaptive Shading Devices – System Development

2.5 Methods Applied for Primary Data Collection

Primary sources of research included the development of KiSS (Design Framework for Vietnamese Adaptive Shading Device Systems). This study further benefited from the evaluation and validation of proposed system through extensive building simulation.

A positivist epistemological stance was adopted for BIM integrated real-time performance monitoring and evaluation, in rationalising the strategy for real-time climate adaptive building response.

2.6 Systems Development

The systems development is perceived as a research process that suits the category of applied science, suited for technical, evolving and formulating kinds of research. Nunamaker et al. (1991) emphasised that systems development is *"a perfectly acceptable piece of evidence (an artefact) in support of a 'proof', where proof is taken to be any convincing argument in support of a worthwhile hypothesis. System development could be thought of as a 'proof-by-demonstration"*; and proved that it has a remarkable capacity that allows practitioners to achieve research objectives via three main stages: concept - development – design realisation.

Principally, imagination and creativity from the concept phase will result in tentative design and operation framework in the developmental stage that finally become research output on the design realisation level. The research process comprises five major research matters; their study steps, as shown in Figure 2.3.

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Figure 2.3 Systems development research process, proposed by Nunamaker et al. (1990).

Specifically, the research process incorporates components in both the social and natural sciences research methods. The interpretation of these subjects suggests that a systems development methodology is both focal and universal. Therefore, it can signify a ‘global-methodology’ which can lead to an order of recognisable ‘local-methodologies’.

2.7 Systems Development in this Research

This research concentrates on all stages of the research process outlined in Fig 2.2 above. The adopted methodology in this research is illustrated in Figure 2.4. Principally, for the first stage, a design method utilising a grammar-based approach for a novel geometric pattern generation is developed; the second stage establishes a generative/computational design system for adaptive façade architecture, using a BIM-based algorithmic approach; in the third stage, the adaptive solar shading system is analysed through a performance-based BIM-integrated simulation method; and in the final stage, design alternatives of the system is optimised and evaluated by a simplified multiple-criteria optimisation method. Notably, each of these approaches will be divided into sub-approaches, which will be described in Chapter 6 and 7.

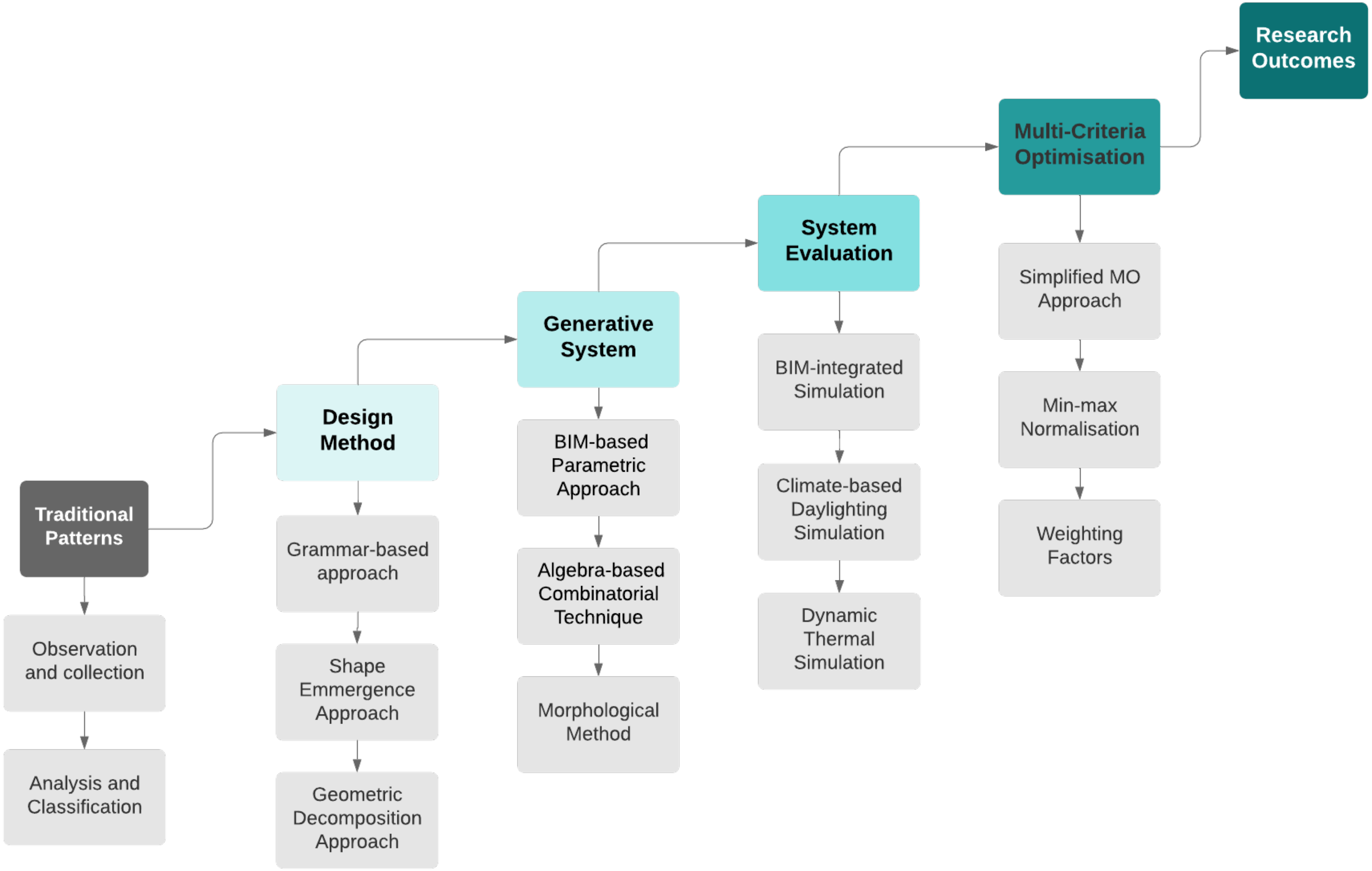

Figure 2.4 Research Methodology. (Source: Author).

In order to reach the goals set out above, the primary objective is to develop a framework for the application of the evolutionary design approach that allows the variability problem to be overcome. This framework is referred to as the generative evolutionary design framework. The framework consists of three parts: a design method, a computational architecture, and a performative architecture.

2.7.1 Design Method – A Grammar-Based Approach

The design method generally describes a design process for transforming the Vietnamese traditional patterns into a new generation, which inherits its ancient aesthetics through implicit rules, under compositional geometries. This procedure is organised as a number of acts to be accomplished in a prescribed manner. Mainly, it exploits an approach for effective design creation – the grammar-based production system (de Jonge and Visser, 2002; Heering and Klint, 2000). Used in syntactic pattern recognition applications, this approach is considered influential in architecture, engineering and product design by virtue of its great capability of analysing existing designs and generating new designs ensuing user-specified rules and requirements without laborious undertaking (Knight, 1995).

The use of grammar-based production system in this study primarily are: (i) in the analysis of existing Vietnamese geometric patterns for the exploration and detection of design languages that can produce the similar style of patterns; (ii) in the revelation and production of stylistically coherent languages for a large set of designs of novel patterns.

2.7.1.1 Grammar-based Design

A design grammar classically comprises:

- elemental vocabularies of existing designs
- grammar rules of an object: A→A’, where A and A’ are vocabulary elements
- an original scheme *S*, ordinarily containing a component or parts of the vocabulary.

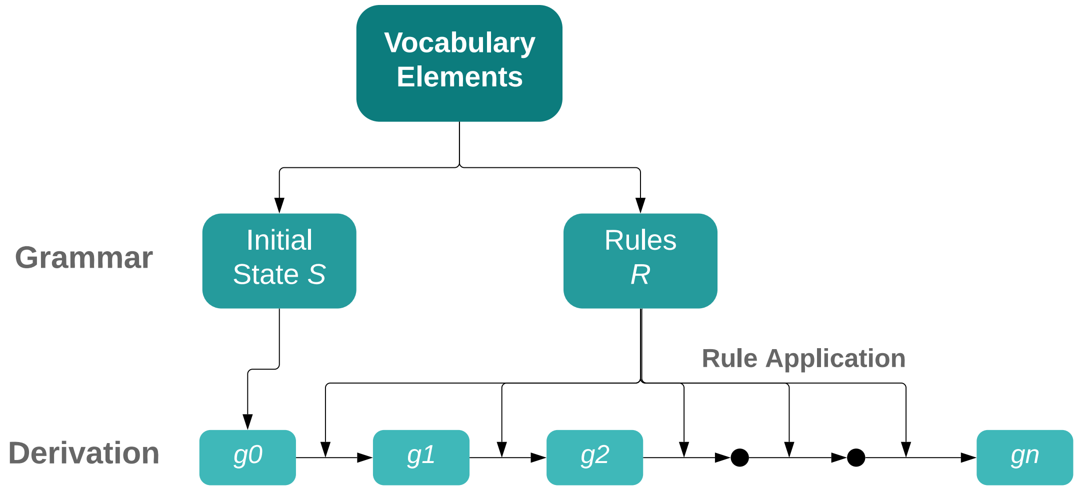

Figure 2.5 Elements of grammar and derivation. (Source: Author).

Specifically, the derivation involves a series of states [g_0, g_1,..., g_n,]; where g_n is shaped by g_{n-1} via operating a grammar rule *R* (see Figure 2.5). Importantly, at any step of a derivation, or at some points of it, rules and matching conditions can be responsively chosen by designers, thus providing the flexibility of interaction between designers and the grammar-based production system, paving the way to potential innovations.

Research in the grammar-based production system is acknowledged in the literature, through a large amount of effort in shape grammars (Stiny, 1980). Two distinctive characteristics of shape grammars are the shape emergence and generative formal grammars (Grasl and Economou, 2013). A combination of both of these will be untaken in this research.

2.7.1.2 Shape Emergence and Geometric Decomposition Approach

Given their essential nature, shape grammars are mostly assembled by humans. This natural process leads to the problems in detecting the language of designs that a computerised grammar can represent (Knight, 1998). A combination of two approaches will be used for the grammar-based production system: Shape Emergence and Geometric Decomposition (see Figure 2.6).

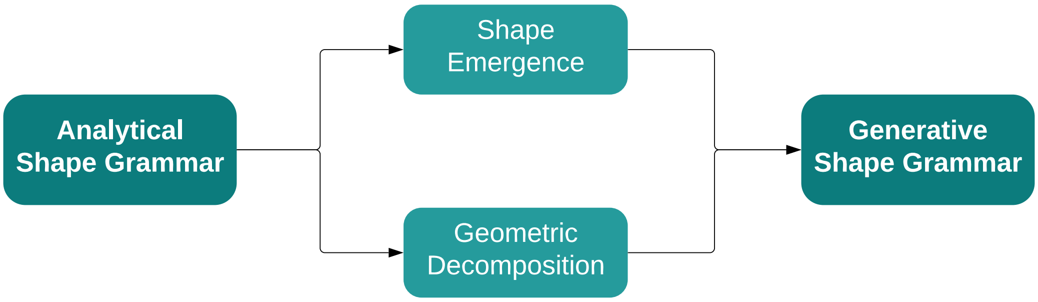

Figure 2.6 Steps in the development and application of grammar. (Source: Author).

Firstly, the system seeks 'generic core' which emerges from the analysis of the given patterns by employing the analytical shape grammars to identify the primary structure and its elemental behaviour. These parts establish a vocabulary of emergence shapes for the grammar-based production system.

Secondly, for evolving pattern design, the concept of 'cores' being infused with the prospective to create a topology, such as structures and forms, derives from the view that the emergence of the topology heavily depends on properties inherent to those cores. Since the new designs are required to be built from understandable arrangements and recognisable rules, which are based on the traditional patterns; geometric decomposition is used to find out their basic structure (for example, a square or a triangular grid) of the existing designs and hidden orders of the generic cores.

Realistically, unlike making grammars by hand, for example, via drawings and sketching, the formation of design grammars has been a developed in a computational environment, requiring programming the grammar rules in a form applicable by computer (Gero and Ding, 1997). The research now attempts to assist designers in formalising the structure rules via a parametric approach by using the programming tools, hence supporting end users to have a computer-friendly deployment of shape grammars.

2.7.2 BIM-based Parametric Approach – A Generative System

The parametric approach aids the creation of a range of designs by changing parameters associated with the overall structure and generic cells. However, the parametric approach is not limited to modest changes in dimensional constraints. Since the cells themselves do not need any modification, the method is used in this research under mathematic-related terms in literature, for example, Algebra and Combinatorics (Tao, 2014). These terms have been applied in the parametric design in various form, for instance, relational modelling and variational design, primarily used in the area of computer graphics (McCullough et al., 1990; Mitchell, 1990).

Although the combinatorial approach is conceivably suitable for pure mathematics, it is considered the most appropriate method for generating forms in this research. This method generates forms through representation and assembly of the cores. The combinatorial program can create a shape by affirming a trivial and neutral state. For instance, a T-shape can be generated from five voxels in a user-defined parametric manner.

With the lexicons of shapes, rules, structures and orders, algebra-based combinatorial technique, the conditions to form an algebra, a grammar becomes an algebra with a supplementary set of rules that transform the cores and operators that combine them.

In order to apply the information of the parametric process, including shapes, rules, algebra and combinations information, to computer implementation, the research requires a mechanism that is able to both handle such amount and types of information and operate the combinatorial acts – Building information modelling (BIM)-based generative system. Broadly, processing data and information integrated into human rationale can lead to knowledge (Carlsson et al., 1996), and the ability to decode data and choose valuable information for decision-making. In fact, whilst it is not easy to explicitly clarify the order of data – information - knowledge, a process of gathering data can extract practical information, allowing knowledge to be inserted into decision-making.

Also, BIM offers semantics that supports properties comprehensively within design models, both in terms of qualitative and quantitative aspects, particularly the aspects that are not graphically perceptible. Additionally, semantics involves a large number of types information concerning project location, environmental data (airflow, solar radiation), physical properties (glass transmittance and thermal), geometry (dimensions, area, volume) and weather. Comparable to the fields of linguistics and philosophy, the BIM semantics embrace meanings and relationships among model components since their information is grouped under hierarchies and organisations in the form of families.

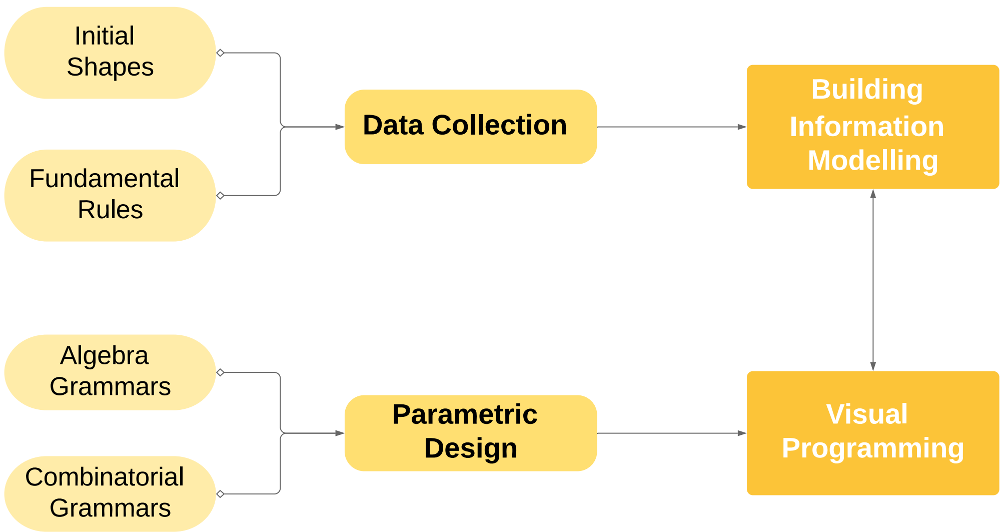

Figure 2.7 BIM-based generative model. (Source: Author).

Figure 2.7 shows the approach of BIM-based generative system adopted in this research. BIM offers an effective way to exploit the generative power, supporting refined design alternatives to be created. Generative BIM can be perceived as the implementation of parametric strategies in the grammar-based design system of this research. Moreover, since the notion of generative BIM is strongly connected to algorithmic and computational design, it has an advantage to allows searching for a variety of design possibilities through programming. By associating BIM with programming mechanism, shapes and rules can be altered explicitly via algebra and combinatory parametric transformation; change of rules and algebra factors can be straightforwardly returned in the change of patterns. This method also allows designers to flexibly shift between the alternatives regardless of their complexity.

2.7.3 Evaluation – A BIM-integrated Simulation Method

Due to the capability of processing and managing information, BIM-based generative system is able to simulate and thus, evaluate its belonging design models to evidently defining which model performs the best or better than other designs, in defending the decision-making. The generative façade shading systems, merely in the form of BIM geometric data, at this point, have no meaning in terms of sustainable performance before they are put in a simulation process. In addition, although BIM platforms offer simplified building energy models (BEM) analysis and simulation mechanisms to carry out basic environmental analysis, the attained results do not provide a comprehensive set of data for validating proposed dynamic shading systems. This is explained by a lack of specific data for internal systems (HVAC and artificial lighting) and external surroundings (solar, weather and construction), which are essential for operations of a dynamic shading device. Therefore, this research requires a methodology for creating a practical evaluation framework via a BIM-integrated simulation method (BSM), which can serve as a tangible '*proof of concept*.'

Here, the approach is proposed as a holistic strategy, which consists of three components, as follows:

(1) Climate based daylight modelling (CBDM) (Nabil and Mardaljevic 2006): calculation of numerous luminous amounts of daylight through naturally occurring situations originated from a typical meteorological database. CBDM provides estimates contingent to the project site, the building positioning, as well as its forms. CBDM regards daily to monthly variations on an hourly basis in a full year. Other climatological changes represented in the weather files (for example, solar radiation and cloud cover) are also integrated into the process.

(2) Dynamic thermal simulation (DTS) (Nielsen et al. 2011): is a method aimed at stimulating the reactions of building to external environmental influences. It takes into account information of occupancy patterns, internal loads, solar gains and HVAC capacity to simulate the whole building's thermal behaviour, for every hour in a year.

(3) Key performance indicators (KPI): denotes the level of effectiveness of factors that are crucial to define the overall functional performance of individual designs. Thus, the designers must have principal benchmarks to measure when assessing operational success (McIvor et al., 2010). While it is widely accepted that the KPI approach primary works for organisational evaluation settings, this method has been verified to be effective for harnessing both qualitative and quantitative schemes in the mixed-method research process.

2.7.4 Multi-criteria Optimisation

The output data from simulations produce a *Pareto front* for multi-objective fitness functions of the system. A *Pareto front* represents a set of non-dominated solutions selected as optimal when no objective can be improved without sacrificing at least one other objective. The system was used to evolve a design that reflected the best trade-off between two conflicted objectives; maximising the provision of effective daylight whilst minimising the energy demands. The process is known as '*Multi-criteria/Objectives Optimisation'* (MCO). This approach derives from the decision support system methods (Ustinovičius and Stasiulionis, 2001), which originates from the field of statistical distribution and probability.

However, there has not been a reliable mechanism for MCO developed for the BIM-integrated simulations which directly produce the finest solution or a set of optimum solutions.

Undoubtedly, the significant quantity of candidates and criteria make the decision-making a challenging task. Thus, the evaluation process requires precise techniques to establish and compare dimensionless benchmarks through the normalisation of their absolute statistics (Peldschus, 2001). The technique used in the research is termed as *Min-max Normalisation*. Additionally, values from such a process must be analysed to conclude the importance or influence of the objectives. This technique is known as *Weighting Factors*. The combinatorial approach of these two techniques helps to manage and processing datasets precisely and eventually making accurate decisions.

2.8 Ethical Issues in Research Undertaking

Ethics are vital elements of research undertaking and most especially among academic institutions. Ethics play a vital role in the planning, design and development of research. The goal of ethics in research is to put adequate measures that prevent anyone from being harmed or suffered adverse consequences from research activities. Given the design nature of the proposed research, its success depends on the quality and quantity of information that are extracted from the developed systems and validated by use of simulation software, hence there are no obvious privacy issues, nor any issues involving involuntary consent of the subjects, exposure of personal identity, and unauthorised access and publication of vital documents by a researcher (Denscombe, 2003).

2.9 Chapter Summary

This chapter presents the research methodology in this Thesis; the rationale for KiSS system development in Chapter 6, the data analysis and validation in Chapter 7, as well as the considerations of research ethics. It investigates the philosophical position of the research with pragmatism as a conceptual platform for design thinking.

In light of this, the research does not try to describe architectural design as a science, instead, it positions its methodology through 'design as research' notion, based on the research by

Nunamaker et al. (1991). Many scholars and architectural theorists, such as Donald Schon, Oxman, and Herbert Simon, have been convinced that the Nunamaker's multi methodological approach to system development, supports innovative thinking on how design science could be defined, theorised, and actualised.

In particular, this Chapter outlines the development of the novel KiSS system and its four key stages. The first stage uses a shape grammar-based approach to construct a conceptual pattern framework. In the second stage, a BIM-based generative system is developed for the implementation of the conceptual framework. Consequently, a BIM-integrated simulation workflow is created to analyse and evaluate the theory, in the third stage. Finally, a multi-criteria optimisation is develop to effectively search for improved solutions from a large pool of domain possibilities.

CHAPTER 3: ORIGINS AND DEPICTION OF VIETNAMESE PATTERNS AND ORNAMENTS

3.1 Introduction

A large number of classic façades have over the centuries served the role of a connection between indoor and outdoor environment via their ‘multi-layer’ façade. In fact, prior to the Modernism era, building façades involved multiple artistic sculptural elements that stretched along the length of the external walls such as columns, bay windows, colonnades, arcades and loggias. Together they formed a three-dimensional transition between the building spaces inside and the external environment outside.

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Figure 3.1 Facades of historic palace Procuratie Vecchie on Venice's Piazza San Marco. (Source: dezeen.com).

For example, the façade of the Procuratie Vecchie in Venice (Figure 3.1) on the north side of the St Mark's Square in Venice, oldest of three connected buildings, functions through its transitional layers, linking the building with the central square and delivering ‘habitable shade’ by crafting different sensual thresholds, for example, diverse areas of warm, cool, bright, and shady spaces. This diversity is extraordinary because it inspires us, both as architects and human beings, and helps us become more conscious of our habitats (Behling and Behling, 2000).

On the other hand, ‘single-layer’ façades, as often seen on modern buildings, in the form of well-insulated curtain walls with large opening glazing, often create closed functioning layouts, which are transparent but isolated spaces. In particular, this modern type of facades has become a predominant style in building envelope design due to its increasing improvement in technology and energy performance, for example, triple glazing windows. However, most of these curtain wall façades are designed as thin layers of glass, thermal coating and argon or other gas infills. These layers typically result in a combined thickness of as little as 100 mm, which makes them ‘single-layer’ facades.

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Figure 3.2 Façade of Haus R128. (Source: wernersobek.de)

For instance, the curtain walls of Haus R128 of German architect Werner Sobek (Sobek et al., 2009), are made of high-performance glazing envelope consisting of numerous invisible physical membranes, for example, insulating gases, heating-mirroring foils and glass, in order to maximise daylight, vision and heat transfer between the construction and external environment as well as dynamic functions of open spaces in modern context (see Figure 3.2). However, Picon (2013a) argued that this kind of single-layer façade is merely an industrial advancement that lacks architecturally dynamic zones; therefore, it does not provide an organic and profound correlation between the two environments. Michael Hensel (Hensel, 2013) proposed reconsidering or changing the design of these façades, emphasising that: “*a single-layer, undifferentiated and flat building envelope will present severe limitations in providing a heterogeneous space and microclimate*”.

In Asia, the trilogy of *nation-identity-modernity* plays an important part in the creation of many modern cities. More recently, developments in Asia have shown a weak connection between *nation-identity* and *modernity-identity* (Abel, 1982; Bernardo and Palma-Oliveira, 2013; Levit, 2008), which needs to be evaluated. In the modern building design in the Western world, the perception of the appearance of contemporary architecture is primarily expressed through the terms of industrialisation. The arrival of contemporary architecture in Asia is considered merely as another version of the West's architecture (Mand, 2013).

3.1.1 Returning of Patterns and Ornaments

In the first decade of the 20th century, the influence of Adolf Loos' statement about ornaments in architecture being 'criminal' (Loos and Opel, 1997), in which he designated working on ornaments as being a 'crime', had made them nearly vanished from architectural design for almost a century (Mitrache, 2012).

However, despite controversial opinions, current works, both in academic research and design practices, has been witnessing a remarkable comeback of the ornaments (Balık, 2016; Picon, 2013b). Indeed, since 2005, growing interest in ornaments have resulted in numerous exhibitions and books (Balik and Allmer, 2016). Furthermore, research in the area of architectural patterns and motifs has been a continuous quest of architectural scholars, and the discourse on their use, nature, cultural and social factors of patterns and ornamentation are continuously growing. It is undeniable in those works that tradition and culture generally are a continuity of innovation (Furján, 2003). This continuity in architecture can be achieved through meaningful designs which renew affiliation between tradition and innovation via ornaments and patterns (Klassen, 2006).

Interestingly, the comeback of ornaments and patterns in architecture is different in several ways. Across the Western architectural tradition, between the Renaissance and beginning of 20th century, ornaments were meant to be local, used to be included as artistic components, focusing on particular parts of building such as columns and cornices. These patterns were also manipulated to express economic and often political intentions.

These days, they seem to be designed as ubiquitous arrangements mainly associated with a creative expression on building surfaces, especially building envelope (see Figure 3.3). A series of broader issues including the relation between architecture, subjectivity and politics is also returning (Balık, 2016). The forces behind this are financial stresses, environmental issues, industrial and technological developments, and innovations in mechanically controlled systems (Picon, 2015).

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Figure 3.3 Façade of Cottbus library by Herzog & de Meuron. (Source: herzogdemeuron.com).

Furthermore, the relationship between technological inquiry, cultural concerns and formal modification can be illustrated as architectural innovation in which, attention to patterns and ornaments are getting a fresh wave of attention. Additionally, ornaments provide identification of a necessity for architectural design.

3.1.2 History of the Traditional Ornaments

Any culture across the globe has a broad set of repeated patterns. On the surface, their differences or similarities can be easily recognised, but in many cases, their structures are complex as several symmetries are manipulated all over their host object (Dalila Mohd Sojak and Utaberta, 2013). Prehistoric patterns, such as the Frieze patterns, are symbolic motifs made up of lines, triangles, circles, and squares sculpted onto the item's surface, imitating along a line. They can be found in a diverse range of artistic objects, for example, potteries and quilts; and in religious buildings, such as the facades of the Parthenon and Hindu temples (Park, 2017).

Owen Jones in his book Grammar of Ornament (1856) illustrates ornamental vocabularies from renowned ancient civilisations, such as Egyptian, Mayan, and Chinese, which share similar repetitions and symmetrical combinations. Nonetheless, styles, symbols, and motifs diverge from each other because their cultures evolved at different time periods.

Concerning architecture, Cohen (2001) analysed the facades and plans of classical buildings in Italy, like Fondaco dei Turchi in Venice, and uncovered their ornamental complexity that contains multiple overlaying of shape symmetries through architectural elements.

More recently, according to Picon (2014), from the era of the Renaissance to the early 20th century, the main objective of ornament was not simply to satisfy the visual aspect. In addition to that, it expressed information about the character and the intention of construction, the wealth status of the owner, an expression of the cultural heritage of society. In the same vein, Siwalatri (2012) mentioned that ornaments were the most popular method during the classical period since the patterns carried not only an artistic purpose but also a symbolic function. Massey (2013) noted that in classical architecture, the ornaments expressed the building's intention, rank, and identity based on the order of pattern, the ratio, the element of mouldings, the pattern decoration structure which originally emanated from history, legend, and the cultural identity. From the Renaissance to the 19th century, Massey stated that ornaments noticeably bloomed with neoclassicism. The traditional order supported modular structure, which subsequently facilitated in the subdivision as well as bringing the perception of proportions. Furthermore, Massey also discovered that ornaments and its style imitated the economic and political conditions of time, such as colonialism for example. As architecture moved into the era of early modernism in relation to rapid development and the growth of use of industrial materials such as stainless steel and glass, it also impacted building's ornamentation. Chrysler Building (1928), for example, is one of typical examples.

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Figure 3.4 The evolution of architectural ornaments from antiquity to the contemporary, with building's names are listed in Table 3.1 (Elrayies, 2018).

The intimate connection between mathematics and architecture, observed at numerous points throughout history, is also associated with patterns, proportions, ratios, rules of transformation, pattern generation and variation. This stems from the fact that different levels of shapes are tightly integrated with one pattern by implicit mathematical rules. Yet, these complex patterns share some fundamental logics of algebras (Ulu and Sener, 2009).

Table 3.1 Ornaments— A timeline.

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During the long-standing history of architecture, the return of ornaments and patterns have been seen numerous times. More recently at the beginning of 20^{th} century, with Arts and Crafts movement, followed by the transformation to the postmodernism in the middle of 20^{th} century, and more recently with the rise of the late modernism and digital age, the façade ornamentation has become once again popular in design (Gleiniger and Vrachliotis, 2009). Figure 3.4 and Table 3.1 together illustrates an overview of ornaments uses throughout architectural history.

In comparison with blank modern façade designs, ornaments are becoming increasingly employed as the means of creating an intimate relationship between people and buildings, a connection to their surroundings. More importantly, the ornaments are perceived as means of achieving visual identity, national, cultural and communal affiliations. The historical value and cultural heritage of the society are demonstrated by ornamentation in specific periods of time. This is the path of architectural connection within an organised narrative under the objective of the building as large artefact, as well as the society (Ahani et al., 2017). Similarly, ornaments function as tools of communication, according to Riisberg and Munch (2015). Finally, Utaberta et al. (2012) showed that ornaments describe in a direct or figurative style, which is controlled by the designer.

Historically speaking, one of the primary ways to express symbolic, aesthetic, and metaphorical significance was through the use of ornamentation. It is the fact that ornamentation has played and continues to play a fundamental role in articulating architectural language. Symbolic ornamentations demand a definite scale of social knowledge and understanding to make sure their application in architecture continues, according to Levit (2008).

3.1.3 History of the Contemporary Ornaments

Prior to analysing arguments about the classic ornamentation, it is worthwhile to signify the contrasting opinions. Many modernists who concentrated on the arguments were in opposition to ornamentation. The new generation thought that the 'honesty' of the form was distorted by ornamentation. They considered the patterns as being "inappropriate" in the form of industrial materials, function, and construction (Riisberg and Munch, 2015). In his 1908 essay and lecture, "Ornament and Crime" (Loos and Opel, 1997), Adolf Loos debated that labour inputs and health are consumed by ornament making. The modern architecture theorist boasted that he transformed the meaning of ornament from a factor of aesthetic to be that of luxury and inferior.

Surprisingly, even though early modernists criticised ornament, in some way, they also conveyed their expression of visual pleasure. Standardised solutions, uncovered configuration, white surfaces, and mathematical formula were embraced. They approved the visual expression of the material itself, its constructional and structural connection; between stone and wood, the reflection of the glass, and the whiteness of paint (Massey, 2013, 2007). It has been illustrated in the geometric pattern on 1922 Le Corbusier's Ville Contemporaine to house three million inhabitants, where ornamentation was originated from operating the constructional and structural processes. It was called *'ornament structuralised'*, a phrase created by Thomas Beeby, based on the connection between structure and ornamentation.

A similar approach involving ornament was in 1951 in Mies van der Rohe's Lake Shore Dive Apartments. The façade consisted of I-shape columns was designed to express an ornamental impact, which was then called *'structure ornamentalism'*. This also was the legit beginning of Minimalism, which was famously quoted as *'less is more'* – Mies van der Rohe's self-proclaimed *'skin and bones'* architecture. Furthermore, as it can be seen from Frank Lloyd Wright's Unity Temple, the structure of the ornamentation originated from the structural unit of the design and was then coined as *'ornament constructed'*. One of most the significant models in this style of ornamentation is Wright's 1924 Ennis-Brown house. Surprisingly, what Loos meant was not to remove ornaments, but instead *'ornate structures'* (Massey, 2009). The category of patterns connected to this type is used ornaments or surfaced ornaments, which can be found in Art Nouveau, as an example. Correctly, rather than eliminating the use of ornament, those modernists reinvented it before postmodernists remodelled it by abstraction techniques, following Mies principles (Massey, 2013, 2009).

American architect and writer Claude Bragdon, similar to Wright, expressed plant structures to geometric appearance and invented a Projective Ornament system (Bragdon, 1915) to create a worldwide language from decorative motifs and geometric shapes, to take a place of the traditional patterns. His works featured windows, doors and other apertures that are screened by the tracery patterns of projective ornament (Bragdon, 1910). Bragdon has shed new light on the interaction among space, vision and subjectivity in 20th century's theories and practices of architecture. In fact, over the past quarter-century, the doors and windows have acquired a special status in architectural theory. Many of them have found their ways to the building facades through the expressions of innovative patterns (see Table 3.2 and Table 3.3).

Table 3.2 Ornaments on buildings in contemporary architecture.

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Table 3.3 Ornaments on buildings in contemporary architecture (continued).

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More recently, journal articles have emphasised a specific modification in the view of ornaments in architecture, where they are strongly motivated and promoted. In Emma Fairhurst's RIBA thesis, "Rejection or Reinvention - The Decriminalisation of Ornament" (2007), ornaments in modern architecture are more than decorations, they are becoming methods for expression, as well as social reflection. Fairhurst also showed that digitalisation and high technology support connecting "structure ornamentalism" with artistic values. She stated that contemporary ornaments play a key part in modern materiality and the methodology (Elrayies, 2018).

According to Picon (2014), the subjective judgment of the modern ornament is indistinct. The subjectiveness of ornamentation leads to difficulty in terms of interpretation. Picon emphasised that the high-tech industry brings to the attention to modern designs and industrial production. In his opinion of materiality, it is figured as a device, not an intention.

As compared to materiality, immateriality has closely connected to the physical world. Therefore, materiality is limited to particular humanitarian as well as cultural situations. Moreover, digital technology is the main reason for ornaments to arise again. The re-appearance of ornaments in modern architecture is definitely considered to the contemporary technology (Balik and Allmer, 2016; Mitrache, 2012), in the meantime, Le Corbusier disagreed ornamentations in construction as a cumber to social conditions, and decoration has been a practical proof.

Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) have called for the modern technology-attributed computer programs for architects to deal with sophisticated motifs throughout explaining ornamentations, complex textures, and colour scheme into their projects. Parametric design and its digital manufacturing processes include laser cutting, computer numerical control (CNC) milling, robotic layering, water jets and 3D printing. Structural creation required the employment of ornaments among iterations, and mathematical similarity to succeed in proving structural and building performance as well as environmental capabilities, without detriment to an artistic beauty (Balik and Allmer, 2016; Picon, 2013b, 2013a; Tatla, 2018).

Patterns play a fundamental role as an architectural expression in parametric architecture to represent advanced adaptive ornamentation (Schumacher, 2009). Levit (2008) expressed that a pattern is one of the elementary templates of ornaments, comprising materials, patterned-colours, structures, assemblies, and pattern makers. During the monopoly period of images on architecture and the modern development of visual communication which captured society's attention, leading to the establishment of contemporary cultural tendency.

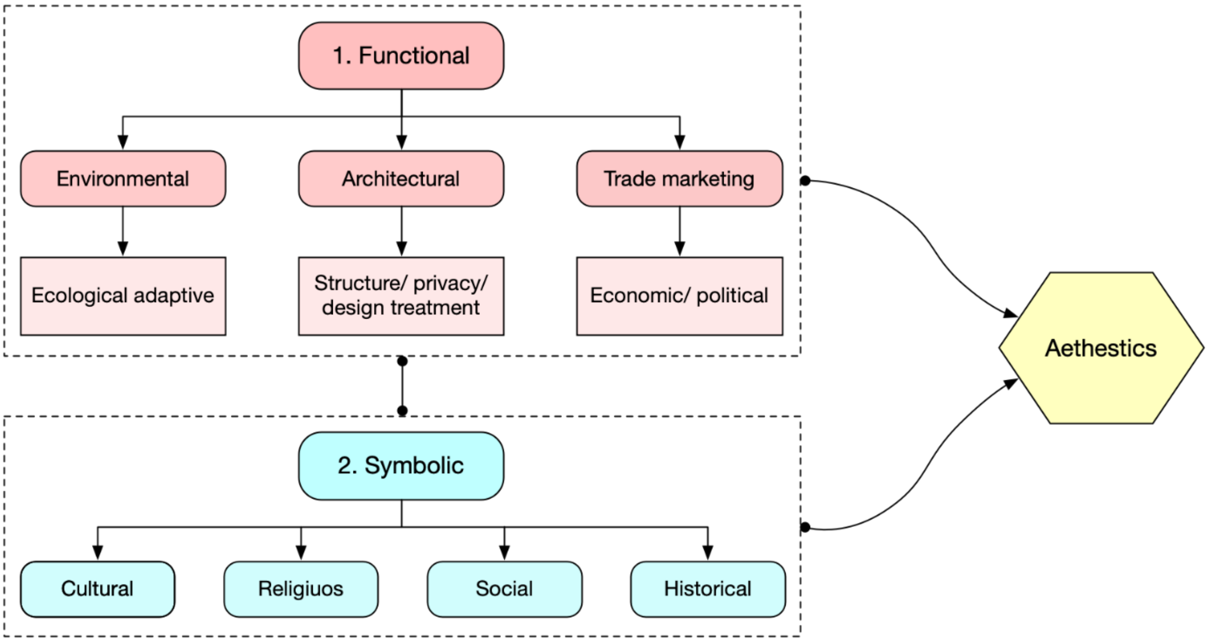

Figure 3.5 Aesthetics' formation in the contemporary architectural facade. (Source: Author).

It is not difficult to understand that the aesthetics of constructions has been created by the traditional ornaments, which have made and represented the history and social culture of own place. They are an attractive and ideal destination for tourists and inspire artists, art historians, tourists, writer's enthusiasm and passion to compose, invent, and discover artistic compositions. Nevertheless, those aesthetic value, historical and cultural intentions are not categorised as an aspect of architecture. It is entirely realistic that the renaissance art of ornament has established in modern architecture. Additionally, is it considered that architectural constructions and ecological works were competed or exceed by contemporary decoration? Analysing this question will be found in the influence of literature review and analytical searching.

The evolution of humankind is captured by the improvement of ornaments in architecture throughout history. In the primaeval period, the skills of human primarily originated from handicraft, which had been profoundly impacted by ornamentation. The expansion of technology and industry, which was reasonably impacted on architecture, including the ornamentation. It is probably to understand that ornaments are eternal. Ornaments have been customised or modified due to the cultural conditions and technological movement.

The ornament was decried by the modernists because of its decoration or the actual components are attached to buildings without any reasons. Nevertheless, there are some discrepancies for modernists to design their own constructions to make sure the aesthetic vision. At the same time, the rest of modernists reformed contemporary decorative patterns substitute the old ones. Many specialists disproved the reality that traditional decoration is simply large decorative parts which are linked to façade. They have mentioned to them as starting from the cultural value, heritage, and the configuration of the building. The outcomes of the analysis are closely connected with the current arguments as well as requirements which have been analysed (see Figure 3.5). The searches literally affirm that contemporary ornaments created as an influence of:

Function: Next to architectural, structural and constructional function are environmental too, which originally come from ecological and climatic matters. The impact of weather in the cities has led to the establishment of eco-friendly architecture; therefore, ornaments have become elements connected with the building's adaptive shading to qualify the better requirements for the urban environment. Modern ornamentation becomes a transitional symbol for the relationship between the construction and its public background. As a result, it plays a fundamental role as an eco-friendly active or passive adaptation strategy, considering climatic variations, which is able to maximise the energy efficiency of the building.

Articulation or expression (symbolism): It is true that culture, history, society are described via modern ornament. The contemporary decoration is an intermediary element to illustrate the relationship between national history and cultural, traditional, religious heritage. Symbolism is an elementary way to present their relationship.

Aesthetics: There has not existed the difference in the appearance of ornament during the architectural period. Whilst ornamentation styles can be variable; the fundamental essence keeps remaining. Henceforward, the ornamentation was and has been an illustrational device which indicates to human evolution, culture and religion, identity as well as economic conditions, and the knowledge of human about the environment. All of those are primary elements which identify people, cities and countries.

3.2 The Role of Culture in Promoting Architectural Identity

Vietnamese aesthetic graphic art combines classical individual mastermind and fresh and skilful art. Their quintessential art is unique, impossible to combine with other aspects from different cultures. It is considered that architecture plays a key role in preserving the value of traditional and cultural heritage, therefore, cultural and architectural uniformity can be considered in the international context. The correlation between culture and architecture is articulated by four descriptions in Table 3.4.

Table 3.4 The model of the relationship between culture and architecture.

Architecture and culture	Architecture	Scope of culture
Functional	As a result of social components interaction	Sociology
Conceptual	As an artistic product that includes an end elevation of the mind	Aesthetics
Functional Conceptual	As a matter of human's life and includes and effective on actions	Anthropology
Perceptual	As a result of mental attitude to the surrounding built environment	Psychology

What was described as a culture (rules, values, etc.) were only parts of the culture of any community. Culture has another aspect called material aspect indicating to the buildings, factories, etc. In fact, these things are considered as a part of the culture of a society. Because it is rooted in the values, beliefs, etc. and from here the link between culture and architecture can be seen. Buildings are like a book covered with dust which should really go and read them.

In this way, the culture of people and the society in which they were built are identified (Parhizgar, 2003). The most important factors for the emergence of different architectural schools are the turning points in the culture direction and creativity. Each culture and civilization start from a point in which the old ones stopped faced with a crisis. However, its direction is to follow and develop old and historical directions and at some points rebuilds its structures. Due to direct effect of culture on architecture, it is natural that cultural changes cause transformation in effective concepts and theories in the appearance of the architecture and consequently, different ideas of architecture comes into existence that determines the interaction between theoretical concepts and methods of culture in general and specifically the theoretical concepts and architecture (Diba, 1999). Every society has its own culture, upon which its foundation of architecture was established, and its architecture is the objective image of its culture. In fact, architecture was and is a true measure of a nation's culture. The culture of the community is responsible for the ways that spaces get formed.

In Vietnam, architecture has passed through dramatic transformations since the 1945 Revolution, when France, America, China, and Russia took their chances to make an influence on the country. Its architecture mirrored all these layers of political, economic, and cultural changes (Galla, 2005; Gegner and Ziino, 2011). Indeed, these conditions led to the deepest change to Vietnam – the '1986 Reform', which was born from the idea that 'Vietnam wants to be friendly to the world' and in the hope that 'no wars will ever happen again on this land', has brought capital gains and culture losses to the country. Actually, cultural transformations, technological shifts and socio-political opportunities all have gone for modernisation and profits (Gainsborough, 2002). As a result, architecture firms have become revenue-generating businesses. Yet, the equation 'office growth = market growth' has not completely been correct. Despite the professional expansion, the Western influences have blurred rich architectural heritage as well as national representation in Vietnam (Gomes, 1994).

The balance can be restored by supporting design language that is Vietnamese in philosophy and style, and socially grounded in the context of modernity. This is essentially dependent on the way architects address architectural elements and vocabularies and provide productive interactions for cultural exchange between Vietnamese and Western styles and enhancement for a 'culture in motion' model.

3.2.1 Architecture as a Symbol of the Culture

Every single social community under the management of classified procedure, and any theoretical ideas creating it has its own objectives and targets. The primary role of architecture in this way is to transform those ideas. As stated by Herman Motsios, architecture was and is the ‘ruler’ of culture in the country. Scruton (2013) in his book “The Aesthetics of Architecture” states that any architectural heritage satisfies the purpose through its appearance; therefore, it becomes a standard aspect of perceived cultural values. In a way that each and every construction is a cultural symbol and evidence, whatever its concept is.

Architecture is manifestation of the culture of a society over history; a pure reflection of the development of civilisation; and ‘cultural burden’ (Abel, 2012; Baydar, 2004). Also, architecture is created to exhibit the traditional values within itself, thus, it is considered as an identity factor of culture (King, 2004).

Figure 3.6 Engravings showing scenes of Chinese life: "Ladies of a Mandarin's Family at Cards" and “Boudoir and bedchamber of a lady of rank” by Thomas Allom (1858).

For example, English architect, artist and topographer Thomas Allom and William Chambers, in pictorial books ‘China, It's Scenery, Architecture, Social Habits, &c. Illustrated’ (Allom, 1858) and ‘Designs of Chinese buildings, furniture, dresses, machines, and utensils’ (Chambers, 1757), in the 18th and 19th century, presented the West a vision of China as thorough as it could be. Architectural components such as screens, doors, and furniture arrived in different angles where subjects played various traditional customs (see Figure 3.6, Figure 3.7, Figure 3.8). Interestingly, these paintings of architecture have made substantial impacts on social perception, thanks to visual, symbolic power of the architectural proportions. To date, many Western Chinese decorative studies are motivated more by the works of Allom and Chambers than by books of Chinese art (André-Pallois, 2017).

Cultural factors affecting the formation of architectural spaces:

The formation of architectural spaces under cultural interaction is represented in below two features:

- In the form of establishment of behavioural regulations and tenet, which directs to functional organising and spatial hierarchy.
- Based on the form of archetypes, metaphors and symbols create from thoughts, ideas, and physical indication which guide to designing meaning in the architectural sculpture.

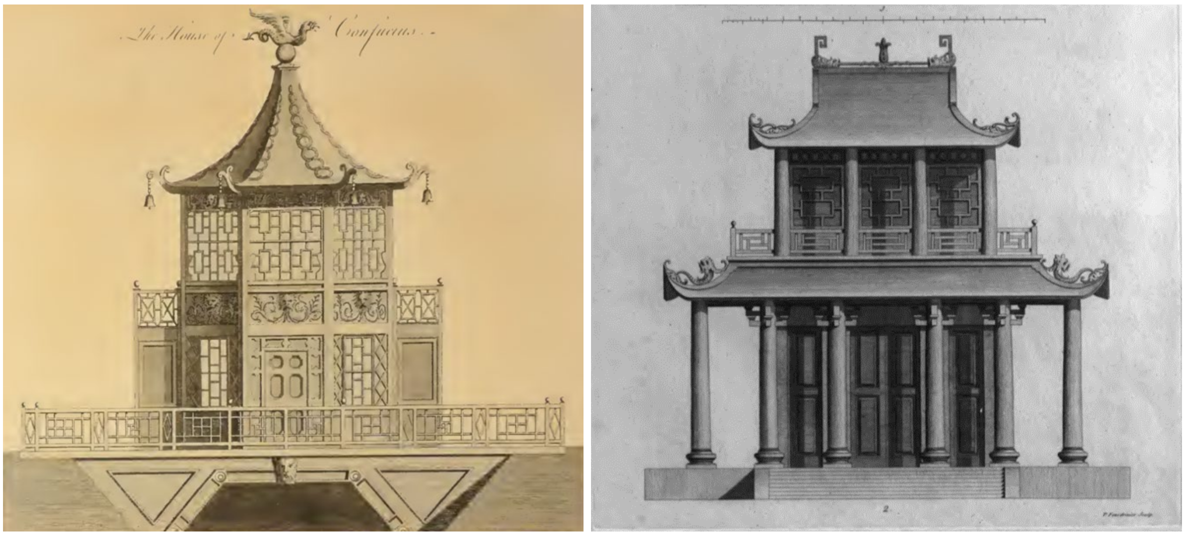

Figure 3.7 Left: “House of Confucius” at Kew garden (Sir William Chambers, 1763). Right: A Chinese temple (Chambers, 1757).

Figure 3.8 “Jugglers Exhibiting in the Court of a Mandarin's Palace” and “Pavilion and Gardens of a Mandarin, near Peking” (Allom, 1843).

In Vietnam, there is an agreement among architects that there is a symbolic hierarchy of elements and vocabularies that represent traditional Vietnamese architecture (Truong and Vu, 2018; Vu, 2019), but what is not clear is whether they should be reused or not (To et al., 2015). This study supports the reuse of these elements and vocabulary because it can connect traditional architecture with contemporary architecture, and harmonise Vietnamese style and Western style in the 21st century. The question is how to use them.

3.3 Current Trends in Façade Design in Vietnam

The reality of industrialisation and urbanisation were first manifested by impressionist artists. Affected by impressionism, twentieth-century art intended to assimilate the machine and techno-centric society (Smith and Smith, 2015). Advancements in science and technology promoted the definition of machine influenced aesthetic, which admired beauty in the rational motions. Thus, different techno-centric art movements such as futurism, constructivism, Bauhaus, and 'kineticism' were established in art and architecture (Simon et al., 2008).

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Figure 3.9 Contemporary façade design in Vietnamese modern residential design. (Source: Archdaily.com).

However, that trend of kinetic design is yet to come into architectural practices in Vietnam. The facades are built fixed; despite the advantages of static shading devices that have been traditionally used (either for aesthetic purposes or for functional reasons), they still show limitations in daylight performance. Many studies have indicated that problems of traditional shading methods can be solved by shifting from a static state to a moveable and adaptable concept (Na et al., 2013). Figure 3.9 shows some contemporary design of Vietnamese residential facades, which reflect only the art side of design. They are meant to show attempts to creating dynamic kinetic beauty, creating the feeling that some elements of those facades are moving.

Fixed shading devices are static elements in terms of geometries, material and visual characteristics. They can calm down the direct solar irradiance and send adequate amounts of diffuse light into deep spaces (see Figure 3.10). In doing so, static facades decrease glare, enhance visual comfort and reduce cooling loads. These systems are divided into three types according to their design methodology: (1) conventional, (2) stochastic and (3) parametric models.

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Figure 3.10 Housing facades with simple patterns as a mean of daylight filter and natural ventilation enhancer. (Source: Archdaily.com).

Conventional design of fixed shading devices includes simple design models of fixed shading devices that are optimised based on a single variable methodology. They take different forms, such as horizontal overhangs, louvres, vertical fins, solar screens and egg-crate models. One example can be seen in Figure 3.9-left. This type is widely considered in academic works of scholars and specialists in the field of the built environment. It applies the inherited characteristics of classical compositional rules, attempting to mimic them. Subsequent designs are direct replicating practices of utilising complete examples of elements from traditional designs. Further examples of this type could be seen in the pottery workshop using brick and bamboo in Vietnam's rural area (Kwok, 2016) and geometric glass curtain wall in Saigon (Block, 2017).

Stochastic design in fixed shading devices is developed through randomly determined patterns by designers that are seen as a new generation of facades evolved from conventional design (see Figure 3.9-right). This type of design is increasingly attracting architects and designers in Vietnam since it is new, easier and cheaper to build than the real parametric ones. It also reveals a new 'spirit' in design that Vietnamese building facades want to and are trying to be parametric. In effect, rather than simply being copied, elements and vocabularies from traditional designs are learnt, resembled and slightly modified to produce designs in a similar style but in modern fashion; for example, see brick perforated façade in (Angelopoulou, 2019) and plant-covered metal screens in (Astbury, 2019a).

Figure 3.10-left shows an example of a parametric design type, which originated from mathematics, implies the use of variables and parameters that can be modified to affect design outcome as a whole simultaneously. Most parametric designs are often used for aesthetic demands but rarely adopted for sustainable design purposes because the application of complex geometries presents a challenge to architects not only in terms of design but also in improving their environmental performances. Vietnamese parametric facades designs are rather simplistic, low level of complexity and still use conventional patterns, which can be seen everywhere in the country. Yet, to an extent, these designs attempt to show cultural identity in a technological manner, trying to match the dynamic relationships in traditional designs without directly copying their shapes. For that matter, designs of latticed walls and vertical hanging gardens in (Mairs, 2015), perforated brick shading device in (Astbury, 2019b), and concrete blocks shading façade in (Liez, 2017) illustrate the beginning of a departure from being tighten up to the old metaphor and fresh experiences of Vietnamese contemporary architectural identity.

3.4 Vietnamese Traditional Doors and Windows

The climate of South-East Asia is hot and humid; wind and airflows make significant impacts on buildings and indoor comfort, vernacular architecture in all countries in this region, including Vietnam, is very spacious and contains many openings on numerous layers, by means of wooden carved windows and tall doors (Nguyen et al., 2011). These layers of openings act as a natural filter, which keeps air movements and daylight availability at the right levels. As a result, indoor air humidity and temperature are reduced, and sufficient daylight is maintained throughout the house, all day long. Sizes and positions are the key controllers; even though they are fixed on each opening, the vertical poles, located on the height of upper part of the human body, divide airflows into 'smaller parts' allowing them to enter almost every corner of the house. This is a simple approach used for tropical vernacular houses but has been extraordinarily useful for centuries. Also, in order to protect the inhabitants, and to block birds and small animals entering the houses, window and door openings are equipped with wooden grids which then evolved into a sophisticated branch of applied art – often referred to as the Chinese lattices (see Figure 3.11).

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Figure 3.11. Rotatable doors and windows act as curtain walls in a vernacular house (Chen et al., 2008).

Although suggesting China as the place of origin, Chinese lattices can be seen in many other countries in Asia such as Korea and Malaysia, and Vietnam (Majewski, 2008). For example, Kim (2006), Lee et al. (2008), Cho et al. (2014), and Lee (2014) examined and proved methods used to control the Korean traditional architecture's indoor environment through analysing the doors. The works of Yuan (1991), GhaffarianHoseini et al. (2014), Doris and Kubota (2015), and Kubota and Toe (2015) revealed that Kampung houses of Malay timber vernacular built environments have achieved a cool microclimate by night ventilation and good solar control of window and wall shading. However, numerous aspects of Malay kampung pattern screens which exemplify key vernacular meanings are lost, yet many Malay residents desire to live with their own traditions.

Vietnamese ornamentation could be geometric, vegetal, and animal patterns. The patterns on doors and windows could either be combinations of these types or are simply geometric, in the style of Chinese lattice (Trần, 2014; Ung-Tieu, 2011). These geometric patterns – the main type concerned in this study, are composed of all types of Euclidian geometries, from lines to polygons (Cadière, 1919).

Historically, large doors with vertical poles began to appear in the Le periods (1427–1527) in Vietnam, and such doors and windows were often covered with bamboo curtains (Chu, 1996). Today, in many Vietnamese houses, Chinese lattices are used not only as protection and filter openings but also as screens of large interiors or as decorations on walls and in furniture (Hartingh and Craven-Smith-Milnes, 2012). However, Vietnamese lattices, which originated from China, are geometrically slightly different. The Vietnamese designs have simpler structure and rules. This can be explained by the differences in weather, architecture, and culture: Vietnamese houses required more air movements to adapt to higher humidity; they had higher vulnerability to weather and shorter life cycle due to the wars; and people wanted to use less resource of materials to build their light weighted and easily assembled houses. Moreover, Chinese, Korean, and Japanese windows and doors often involve an additional layer of traditional paper, so-called venetian blind and roller shade, either integrated or separated, to increase privacy, noise cancellation, and air-tightness in the regions of cooler climate which has a cold winter (Lee, 2013; Yoshino, 1986). However, although lacking of direct sunlight, large opening ratios on the doors and windows help distribute diffuse light adequately for the rooms (Lee et al., 2008). Because of the tropical climate, Vietnamese ones, similar to Thai and Malay versions, do not have paper layer in order to maintain air velocity around the house for cooling and dehumidifying means (Athapitanonda and Brian Mertens, 2006; Chuki et al., 2017; Jotisalikorn and Phūmathon, 2002; Trần, 2014; Yuan, 1991). While Chinese and Vietnamese doors and windows mostly are single/double swinging, Japanese ones are often sliding, featuring the Japanese simplicity style of living and sophisticated carpentry techniques (Miller and Wilk, 2005; Ozaki and Lewis, 2006).

Content removed due to copyright reasons

Figure 3.12. Left: Old painting shows the curtain door's popularity. Right: Curtain doors with three different apertures.

Interestingly, although being Chinese modified, the Vietnamese designs could still impress a mathematician or a computer scientist with the hidden mathematical patterns behind their humble squares and rectangles. This is also the case in the art of most of the Arab countries and well-established cultures. Fascinating compositions of patterns that have a strong mathematical background could be seen, for example, on Iban kilims, Indonesian batiks, African pottery, New Guinean tapa rugs and many others. Those geometric patterns were critical in their cultures in order to express their religious ideologies, through which people show themselves to their gods (Majewski and Wang, 2009). Possibly, their creators did not have the slightest idea of what a mathematician could see in their artworks.

Being a rich source of geometric forms, Vietnamese lattice designs set the main interest in this research. Most of the patterns have a regular structure but somehow look sophisticated and mysteriously diversified (see Figure 3.12 and Figure 3.13). The creation of those designs has depended on the skill and aesthetic sensibility of the craftsmen: a high degree of an artistic process which is heavily dependent on the understanding of shapes and rules. With shape grammar and algorithmic approach combined, new generations of Vietnamese pattern designs can be created.

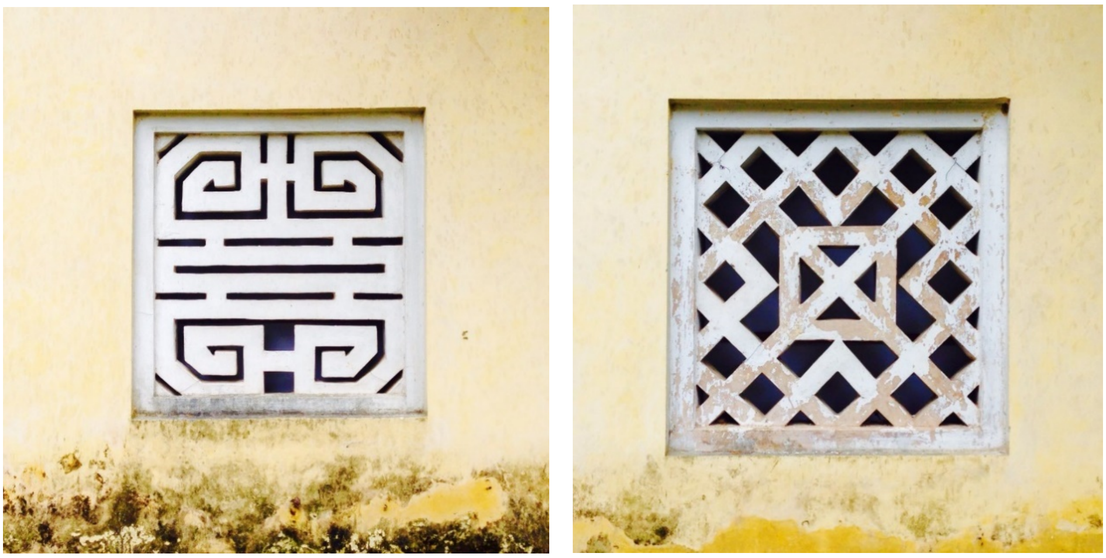


Figure 3.13 Left: Textual type pattern window. Right: Geometric type pattern window. Patterns include opening as a mean of light filtering. (Source: Author).

3.4.1 Shape Classifications

There is a wide diversity of types of Vietnamese patterns; however, to the best of author's knowledge, no research on these patterns from an architectural point of view can be found in academic literature. To date, there is no classification of Vietnamese geometric patterns conducted. Classifying them is hard work due to the fragmented occurrence of the patterns. Both in real life and on paper, the patterns do not appear in the form of order or family; instead, they are found randomly almost everywhere, from designs of fabrics, doors, pottery and furniture, to architecture components such as walls, columns and roofs, in the shape of individual artefacts.

This fragment occurrence can be explained by the discontinuity in the development of Vietnamese societies across the history of Vietnam. Its long history of warfare has witnessed a high frequency of rises and falls of many dynasties which broke down the development of education and arts. In other words, the development in arts, including patterning discipline, did not have enough time to evolve and get established. The existing designs are merely created by individual artists with their own knowledge and ability, which is mostly passed from a generation to another and only within their families. Furthermore, the patterning transition has no specific guidance, mostly relying on apprenticeships without studying the inherent structures, which determine their characters, structures, and practical application. Missing specific instructions, the production process of the majority of Vietnamese patterns in modern days is inaccurate.

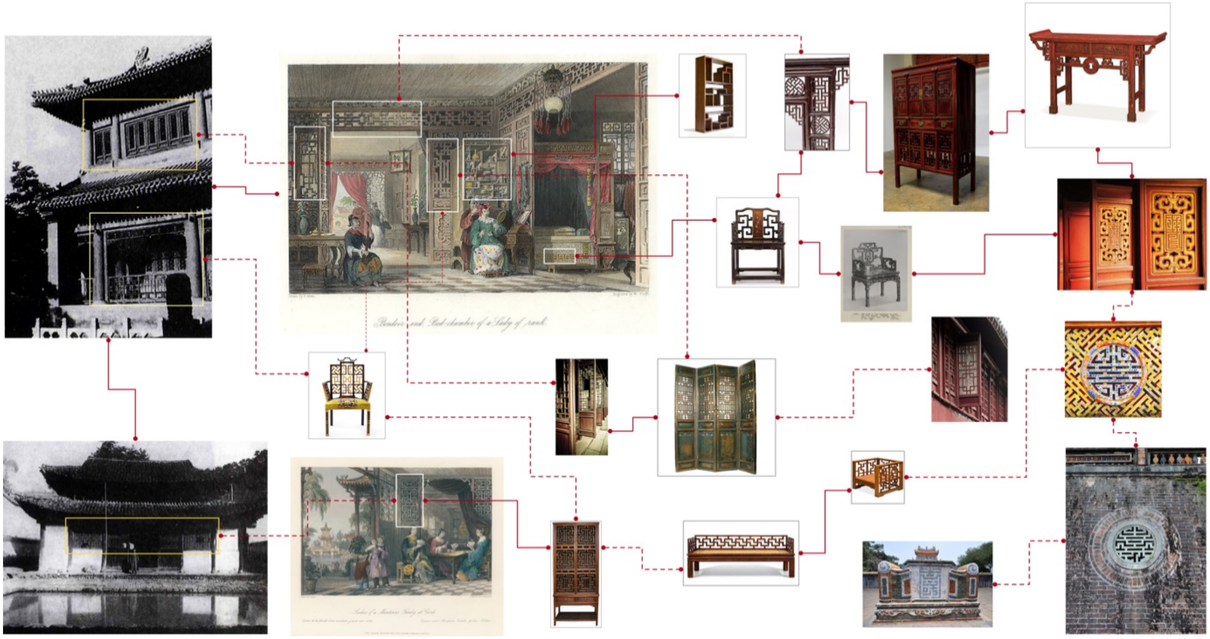


Figure 3.14 Analysis of patterns network. (Source: Author).

Figure 3.14 depicts a diversity of styles of shapes and geometries integrated with designs of architecture, furniture in the form of an analytical network. Most of the patterns belong to the last dynasty in Vietnam. Unlike decorative components in the West. Taking these patterns out will change the entire nature of the hosts, in terms of both aesthetics and functions. For instance, without a pattern inside, a window is merely a rectangle wooden frame; it loses its primary purpose of filtering daylight and natural ventilation.

The patterns are created based on underlying motifs, which originated from religious ideology in a specific society and culture, as attempts to express ancient meanings or wisdom. Most motifs found in Vietnam are rooted in China due to being colonised by this nation for centuries, before Vietnam's independence era (1010 AD). Other motifs highly likely came from India, either Buddhism or Hindu (Zakharov, 2013).

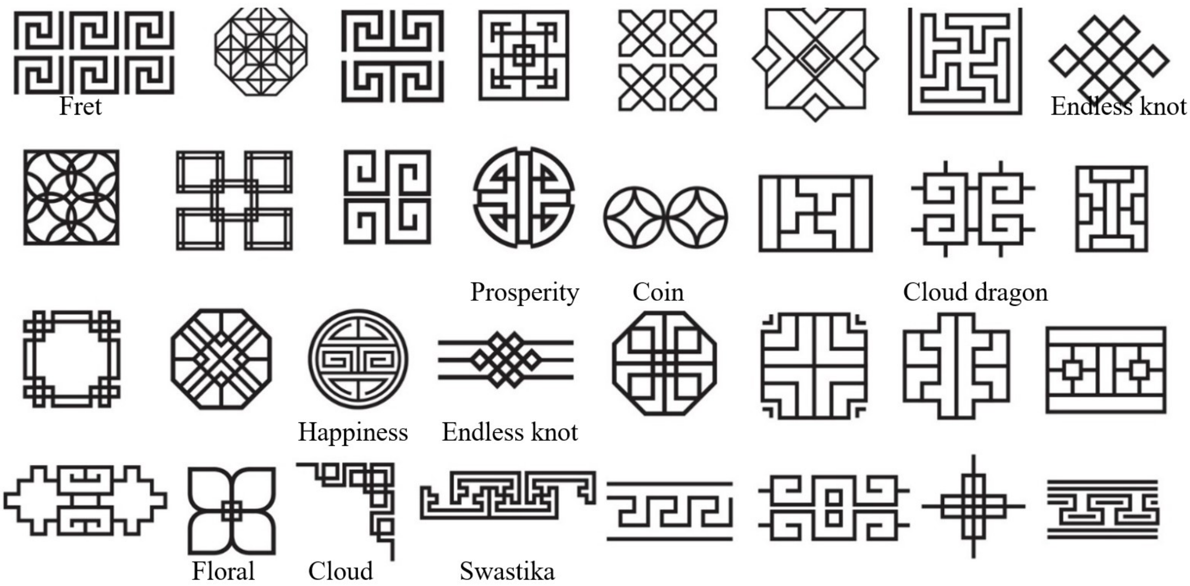


Figure 3.15 The most recognised motifs of traditional Vietnamese patterns and their variations. (Source: Author).

In addition to the artistic, cultural expressions, the artefacts of these ornaments are also recognised as symbolic means for the expression of shared beliefs and desires of the community (Law, 2012). In a nutshell, they hold the promise of wealth, peace and longevity. Besides, the influence of traditional Chinese thinking from Confucian and Taoist can also be traced (Eberhard, 1986; Jamieson, 1995).

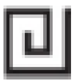
Figure 3.15 shows typical motifs found in Vietnam with some of their names are explicitly presented, and some popular motifs have several forms. The most typical motif – the Swastika is a prehistoric pattern well-known to have a root in India, where it was linked with Buddhism. It denotes many meanings, including the Heart of the Buddha, the acquiescence of spirit, total happiness and power of the mind. In China, Swastika is believed to be "10,000", an expression for countless, or infinity, used initially to express ambitious and eternity of the king (Eberhard, 1986). The Fret is seen everywhere in the world, rooted in Egyptian civilisations. The Endless Knot obtains and promotes wealth; it is also a symbol of seniority, saint's viscera. The Conventional Bows or folded Sewed Altar Cloth is a figure of serene partnership or Embroidery as a Fine Art. The rainbow motif is a manifestation of transient enchantment. It is also promising and contains a mystical thought - the pass of a grandmaster and his resurrection. Somewhere else, it is stated as the 'body of light' (Jones, 1987). The cloud motifs express fast-changing, the transparency of the sky and also is a visual of the Buddha mind. Clouds arrive and depart throughout the heavens, comparable to the evanescent beliefs, yet the nature of the heavens remains unaffected.

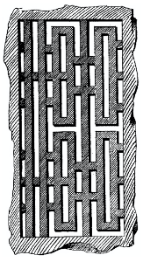
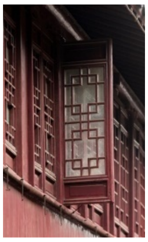
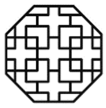
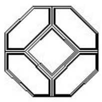
Meanings and expressions of these motifs vary from region to region across Vietnam's territories. As stated before, there are minimal scientific studies and evidence about the existence of the Vietnamese motifs. Papers and documents about them can be found nowhere. This research perhaps is the first attempt towards them in academia. The group of motifs shown in Table 3.5 and Table 3.6 is a result of the author's observation and collection.

Table 3.5 Classification of motifs.

Name	Underlaying	Grid
Circuitous	Quadrilateral	Parallelogrammatic
Primitive rectangular	Rectangle	Rectangular
Centred rectangular	Rectangle	Rectangular
Square	Square	Square
Hexagonal	60◦ rhombus	Hexagonal

Table 3.6 Analysis of shapes and rules of typical motifs. (Source: Author).

Doors	Windows	Furniture	Fabrics	Motif	Shapes and Rules
					- T- shape - Rotating 90 degrees around one of four corners of
					- Fret shape - Rotating 90 degrees around one of four corners of the initial
					- C-shape or combination of two rectangles - Rectangle - Rotating,

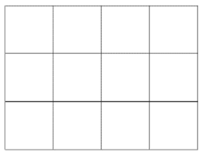
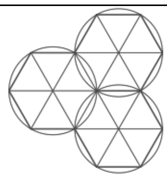
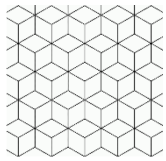
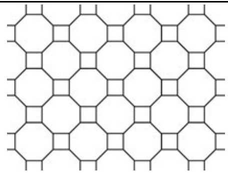
 				 	- Textual shapes (happiness and longevity) - Mirroring
					- Square, rectangle. - Adding, moving.
					- The Endless Knot, square. - Adding, moving.
					- Hexagon - Adding, moving

Majority of patterns is attractive in terms of aesthetics, while technically, their compositions are based on mathematical formulations and tessellation structures. However, it is not always easy to visually detect these hidden structures. Thus, a systematic analysis of them is needed and is described in the next section.

3.5 Analysis of Vietnamese Traditional Patterns

The deconstruction of Vietnamese traditional patterns (VTP) is a method of hierarchically dividing the meta-context of the pattern into individual components of symbolic meaning embedded in the pattern, with transformation functions such as moving, rotating, reflecting, scaling, and copying in a shape grammar. In the publications, Stiny (1977) was the first to analyse and generate the exact style of Chinese ice-ray screens. Following Stiny, Tapia (1992), Ji (2016), and Stouffs (2018) brought ice-ray lattices to parametric shape grammars. Majewski and Wang (2009) analysed patterns from a transformation geometry point of view, looking for symmetry groups are represented and how they can be modelled algorithmically. Also, the studies of Lee and Tiong (2013) and Wu (2012) explained the composition systems of lattice patterns and generated the same designs.

Table 3.7 Classification of Vietnamese pattern grids. (Source: Author).

Rectangles	Triangles	Hexagons	Octagons
			

As a result of the collection in Table 3.6, Table 3.7 classifies four major types of grids based on which, the VTP are built. Rectangle grid is considered the most available while the hexagon grid is hard to find in real life.

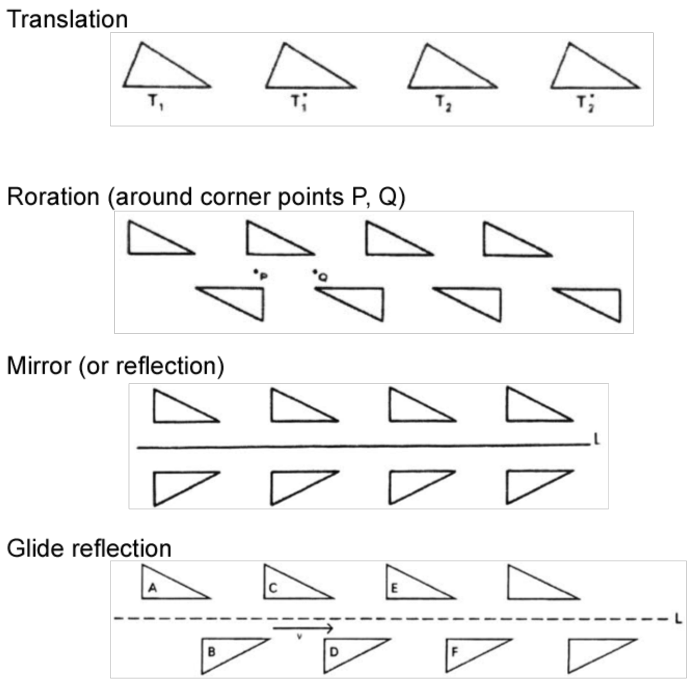
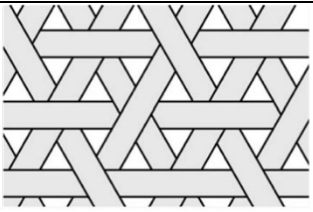
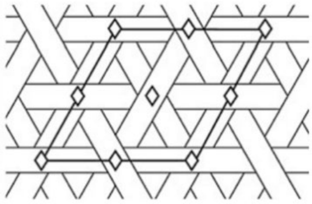
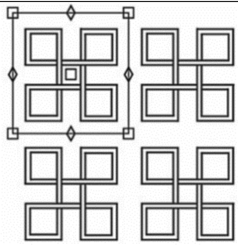
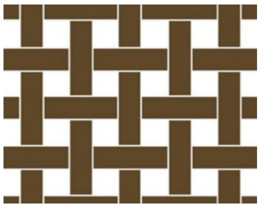
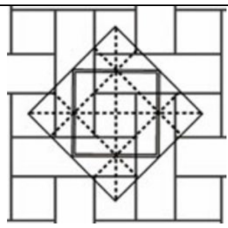
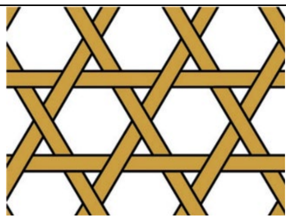
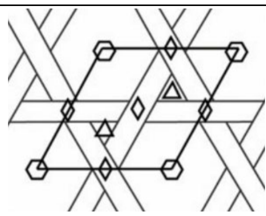
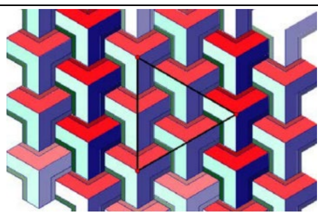
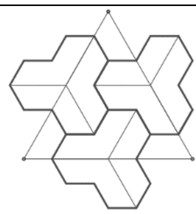


Figure 3.16 The most typical rules found in traditional Vietnamese patterns. (Source: Author).

Figure 3.17 depicts three rules which are used the most frequently in designs of the VTP: rotation, mirror, and glide reflection.

The hierarchical deconstruction starts by defining the symbolic structure of the pattern and applying the traditional Vietnamese patterns construction method to establish the morphological relationship between the components of the symbolic structure, using interlacing point detection method, as shown in Table 3.8 below.

Table 3.8 Visual, intellectual analysis of interlacing points. (Source: Author).

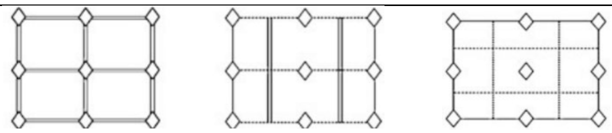
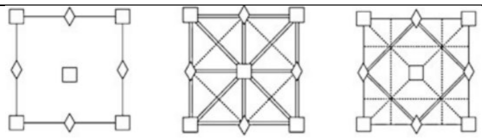
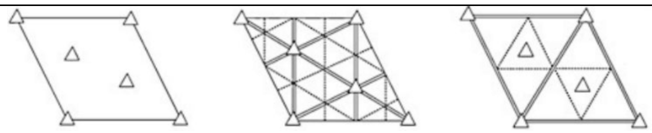
Geometric type	Pattern	Underlying interlace
Triangle		
Endless knot		
Square		
Hexagon		
A mix of hexagon and triangle		

These symbolic structures offer a method of demonstrating the spatial mathematical meaning of the pattern components. The organisation of them reveals the chronological processes of the transformation, which supports the pattern's formation. Also, this approach clarifies the morphological interactions of the 'atom' within the analysed symbolic composition.

Formulating a descriptive grammar of the deconstructed patterns requires the subdivision of all the essential elements of the pattern into the local geometry of traditional Vietnamese patterns, confirming the global geometry. A shape grammars formulation also requires a registration process to establish a catalogue of the set of rules describing the components of the global geometry, which are vital for shape grammar formulations in Chapter 6.

The benefit of the symbolic decomposition approach in this study is to categorise the shapes by particular criteria, granting a more natural, more meaningful selection from infinite substitutes, which can be the seeds of the pattern's innovation.

Table 3.9 Possibilities of shape divisions from interlacing points. (Source: Author).

Geometric type	Shape division
Rectangle	
Square	
Rhombus	

The shape grammars used in the KiSS framework are set to be following these instructions, processing geometries algorithmically and pragmatically, based on analysed interlacing segments and points, classified in Table 3.9. This approach can be a powerful tool for detecting the hierarchical organisations, which are the primary apprehension of style (Knight, 1994), and for assembling a systematic archive, including identified inaccuracies, which help researchers to comprehend the research objective.

3.5.1 Patterns on Doors and Windows

Vital to the process of shape evolution in the KiSS system is the dimensions and shading apertures. These parameters are determined from observation, collection, and measurement methods. Doors and windows are the main objects concerned in this research; their measurements are shown in Table 3.11 and Table 3.12. A number of related works could be seen in (Cho et al., 2014; Lee et al., 2008; Lee, 2014, 2013) for the measurement of daylight distribution and thermal performance by analysing patterns on windows and doors in the

Korean traditional houses, though in literature, there has not been a study that analyses and measures the physical apertures/openings of windows and doors.

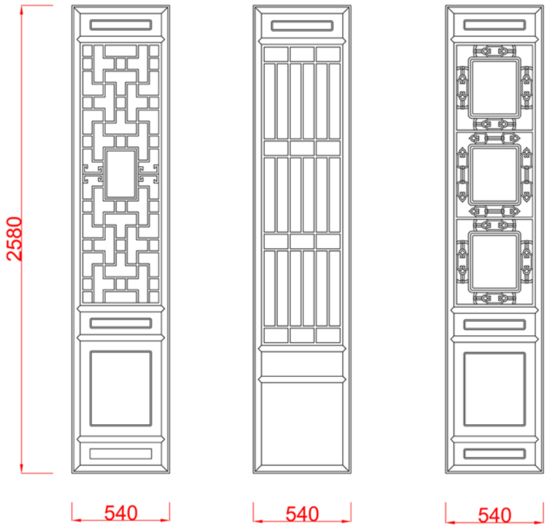
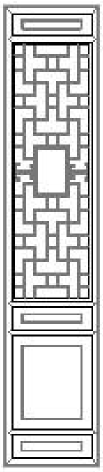
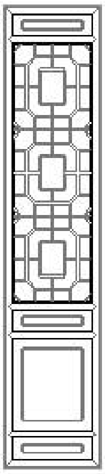
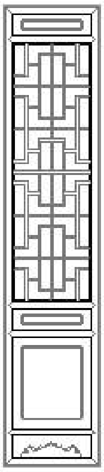
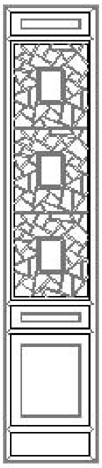
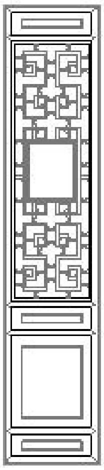
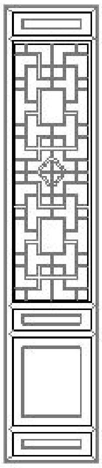
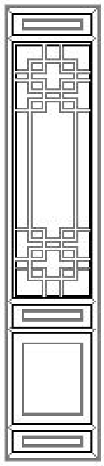
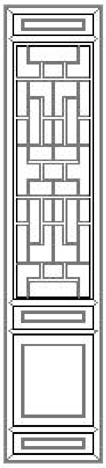
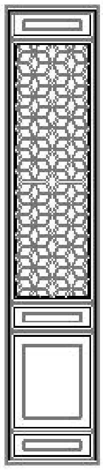


Figure 3.18 Door typical dimensions. (Source: Author).

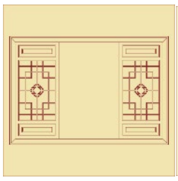
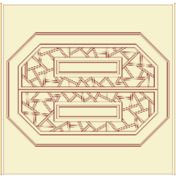
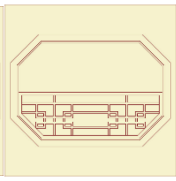
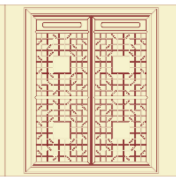
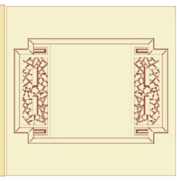
Typical door dimensions are shown in Figure 3.19. This information is needed in calculating doors apertures (see Table 3.10).

Table 3.11 Doors apertures and the thickness of their lines. (Source: Author).

Typical types									
Coverage of the door	41.5%	37.3%	35%	47.5%	45%	42.4%	33.2%	34.8%	48.7%
Coverage of the opening	23.2%	19%	19.7%	34.6%	30.1%	25.4%	18%	21.7%	33.6%
Lines thickness	8mm 10mm	10mm 12mm	10mm	8mm 10mm	12mm 15mm	12mm	15mm	12mm	8mm

Grid type	Square	Square	Rectangle	Ice-ray	Square	Rectangle	Square	Rectangle	Hexagon
Base grid	7x7	6x6	6x7	-	5x5	5x7	5x5	4x7	-

Table 3.12 Windows apertures and the thickness of their lines. (Source: Author).

Typical types						
Coverage of the opening	17.5%	22.4%	9.7%	32.8%	30.1%	8.6%
Lines thickness	8mm 10mm	8mm 12mm	12mm	8mm 10mm	12mm 15mm	6mm 10mm
Window shape	Landscape rectangle	Hexagon	Hexagon	Portrait rectangle	Portrait rectangle	Mixed
Grid type	Square	Ice-ray	Rectangle	Square	Rectangle	Rectangle
Base grid	6x6	-	8x4	6x6	5x7	-

As shown in the tables above, apertures of typical doors vary from around 30% to 45% while the coverages of their patterns upon the doors themselves are between 18% to 35%. These numbers for windows are lower, ranging from 9% to 33%. This information will drive the calculation of generative pattern apertures in Chapter 6.

3.6 Chapter Summary

Classical building facades, composed by well-proportioned ornaments, which establish multi-layer front components, such as arcades, colonnades, and terraces, can accelerate environmental interaction, promote a sense of identity, encourage intimacy between buildings and surrounding community, and allow for an intimate connection between humans and buildings to be formed. However, the ornamentation was rejected by modernists, started by Adolf Loos in early 20th century. Ornament of modernity focused on productivity, simplicity, and consumer values, negatively opposed to luxury, superfluous, and distracting. As such, the modern ornament was expressed by the grain of planed wood, the veining of stone veneer, the tint and reflectivity of glass, and the flatness and whiteness of paint.

Postmodernism in late 20th century has given the ornaments and patterns new meaning, enhanced by the use of parametric and generative design, laser cutters, CNC milling, and robotic assembly, adding geometric patterns into modern facades, in the form of rain-screens and tessellated tiled walls. Renewed with modern techniques and aesthetics, ornament raised up as an interface to address diverse audiences, enhance building performance, and reach new forms of architectural perception. In particular, the visual aspect of ornamentation involves morphology, material and pattern origins, with three main types of motifs observed: geometry, plants and animals. The modern ornamented façade designs have become devices that serve functional, environmental, cultural, and aesthetic purposes.

At the preliminary stage of developing such devices for solar shading system applicable in the context of Vietnam, ornamental motifs and geometric patterns were observed, collected, classified, and analysed, on the basis of qualitative and quantitative approach. Their substances, symbolic implications, and associated intangible cultural value were discussed. Subsequently, the understanding gained from those intangible properties is fundamental for the shape grammars conception, which underlines the generative system of Vietnamese pattern innovation in this research.

CHAPTER 4: SOLAR SHADING DEVICES

"Prehistoric shelters were 'functional responses to local climate, the availability of materials and temporal requirements, nomadic, seasonal or settled".

Horning (2009)

4.1 Historical Development Living Spaces and Shading Devices

According to Horning (2009), historical accommodations are the consequences of local, seasonal, static climatic, nomadic, temporal, and material needs. Laugier (1977, 1755) elucidated how individuals made the rustic cabin for the natural refuge in the Essai Sur l'architecture (An Essay on Architecture). This structure comprises twigs, which shapes slope covered with leaves and mosses to block the radiation of the sun and prevent storms. Laugier elucidated the columns' aesthetics, lattices, and cave structures as the main elements of the Greek temples. For Laugier, architecture derives from reassigning the components of the 'primitive hut' (Figure 4.2 and Figure 4.4) to arrangements of stone and especially from ornamenting it (Picon, 2014, 2013a). He further considers walls the secondary functions, for instance, filling in spacing into a column to protect people from heat and cold and the building's main function is not restricted to structural expression horizontal and vertical loads (Feldtkeller, 1989).

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Figure 4.1. The eight strands of thought related to adaptability plotted relative to a general point in time from which they emerged (Schmidt and Austin, 2016).

The first human need is to get shelter in the form of building and architecture is the art history's oldest form. The men who used to live in hot weathers did not require any occupations and those used woods' scattered pieces for shade and to get shelter from the dews at night. There was not heavy rain and enough cold that make the house bigger than trees. They did not need any labour because they met human needs through the use of soil.

Figure 4.2 The first and second sort of huts (Chambers, 1759).

With the increase in population, the demand of food had also increased, and it became difficult for humans to survive with limited resources that lead to confrontations or disputes, which divided colonies into different areas, and all were in conflict to get proper shelter. Initially, they tend to live in caves that are naturally built; but then darkness and humidity of these places irritated them, and began to exploit them for being healthy and adopt relaxed place (see Figure 4.2).

Due to the need of tools of practical experience, the builder accumulated many boughs of trees, acquired the conic shape and then covered these with rushes or clay to make a hut, enough to make their sturdy secure. However, with the passing time, the skills and expertise of men increased by using natural means. They started to use tools that increase labour due to loss of balance after trimmer and adopted stronger methods of designing; also forms superior to the spool, which is used for particular sheds. It is stated that Vitruvius, properly designed living space with the hut beautify the houses; people used numerous erect trunks lined with timber to comprise the edges, filling up the intervals of time considering the branches tightly intertwined in addition to completed with clay.

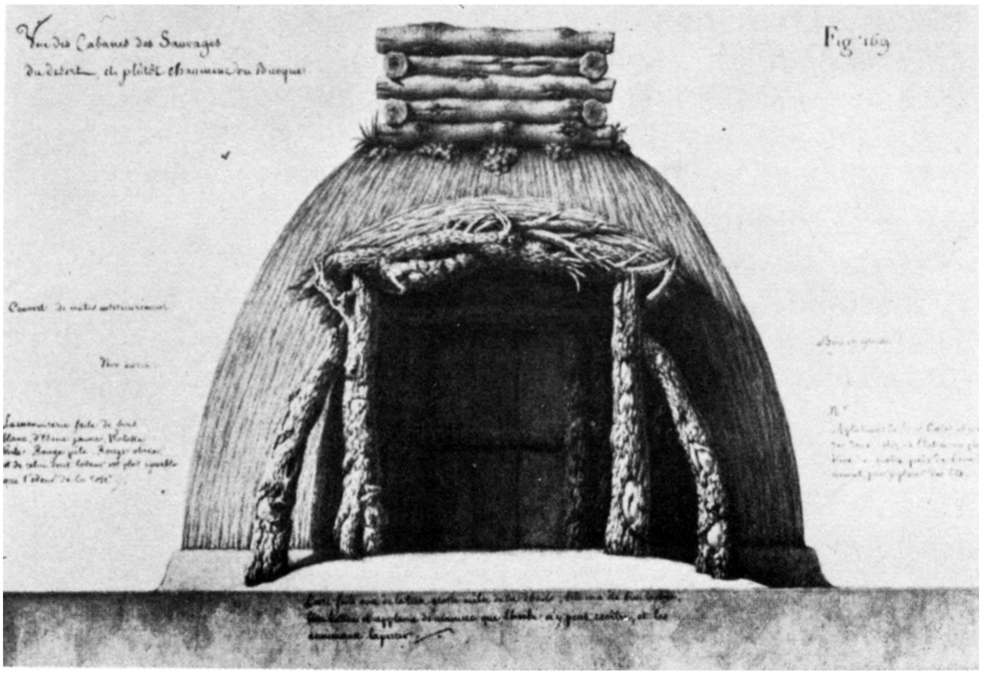

Figure 4.3 The primitive hut (Jean-Jacques Lequeu, 1792).

The concept of Primitive Hut (see Figure 4.3 and Figure 4.4) supports the philosophy of nature, which was popular in the mid-18th century and influenced literature, art, music and architecture. Laugier believes that the simplicity of designing and using natural materials are architectural requirements and well-known ideas adopted by more modern architects, including the vision of Frank Lloyd Wright and Gustav Stickley at Trades Farms. The Laugier's mansion is known as Vitruvian Hut as it is based on the proportions of nature and sacred built by the ancient Roman architect Marcus Vitruvius.

The popularity of Laugier's philosophy is partial because it offers an easy-to-understand alternative to his unimaginable architecture. Twentieth-century architects such as Le Corbusier and the 21st century, including Tom Mayne, recognised the influence of Laugier's ideas on their work.

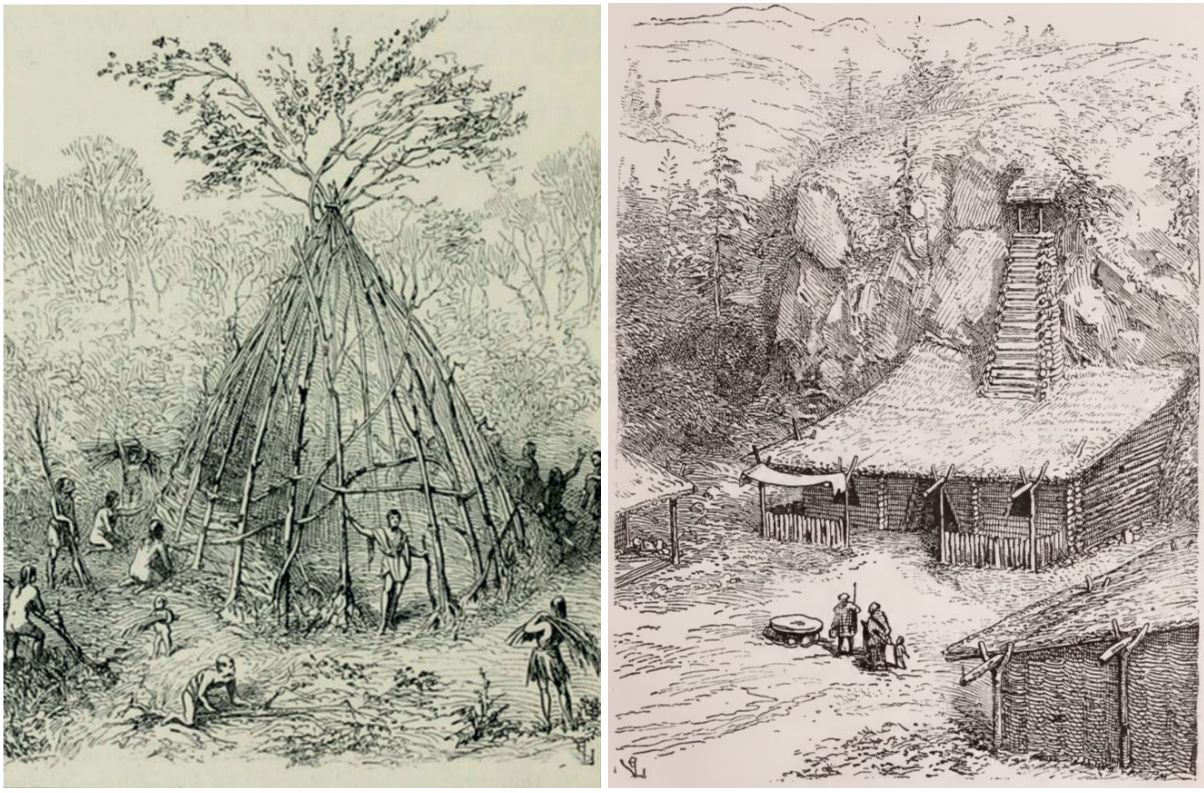

Figure 4.4 The First Building/ Primitive Hut (Eugène Viollet-le-Duc, 1875).

Marc-Antoine Laugier, the French priest rejected the richness involved in Baroque architecture. He made his hypothesis of what type of architecture should be maintained, in 1753. In 1755, Laugier expanded his arguments in the second edition of a book, which consists of the legendary illustrations made by Charles Eisen, a French artist. It is shown in Figure 4.5-Left; a lady shows a fairly outdated and easy-made cabin to a youngster, who perhaps will be a builder. The structure indicated utilising the geometric shapes and normal elements. The Primitive Hut of Laugier is his guidance from the school of thought, and its architecture stems from the primary ideal.

In 1755, translating frontispiece into the English language showed in (Figure 4.5-Right) made by “British engraver Samuel Wale” varies from the presentation created by famous publication in the French language. The picture within the original book is little symbolic in addition to more straightforward as compared to the captivating pictures within the translated book. Both pictures show the approach with reason.

Figure 4.5. The Primitive hut (Laugier, 1755).

According to Laugier theories, men want nothing but protection from the sun’s radiation and accommodation during the storms, and the more primitive type of humans also want the same. An individual wants to build a great home that covers him, although not buries him. Real wood’s pieces brought perpendicularly, communicate them with the columns’ thoughts. The specific bits that may be established after all of them manage to pay for them all entablatures’ thoughts.

Significant incline’s branches covered with leaves and mosses to prevent the solar radiation and storm and after that, an individual is lodged. Laugier concludes that the limited outdated cabin that they had might be the model and magnificence about imaginary design.

With reference to German architect Loebermann (1998), the Chinese wood construction system (Figure 4.6) is built using standard modules and the size system is defined by national regulations. The distance between the centre of the column is measured as a ken that is 90cm, 180cm; making it easy to change and enlarge the structure. The width and depth of each area is a multiple of this standard unit and is made up of the rest of the components such as wood structures, doors and furniture also including area-sized tatami rugs (e.g. Six tatami mats). Traditional houses do not have easy-moving sections, but also retaining walls, which facilitate the replacement of posts and beam structures known as fusuma.

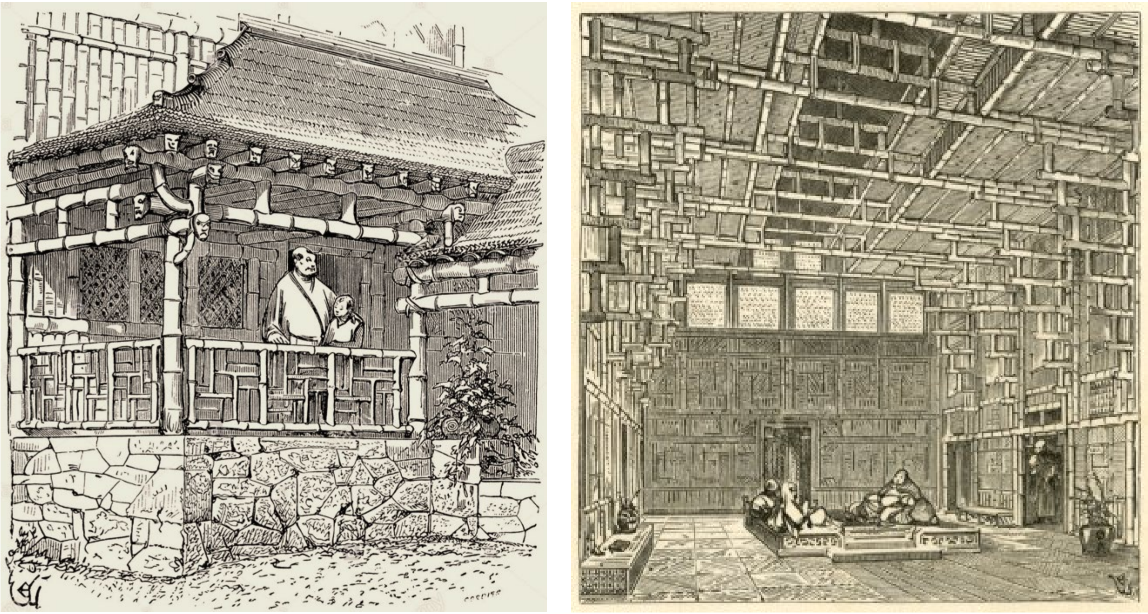

Figure 4.6. Depiction of Chinese home (Viollet-Le-Duc, 1876).

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Figure 4.7. Left: Multi-layer shading system of a traditional Japanese house. Right: a dynamic transition from the house to the garden (Loebermann 1998).

On accounts with, the traditional Japanese-style room infrastructure does not have a functional label (Figure 4.7), but the versatile area, or washitsu that denotes a largely empty stage, which is temporarily self-sufficient for residents. Therefore, Japanese culture defines buildings temporarily and gives the building a mind-set that can be easily transformed by lightweight materials and non-permanent physical connections.

Table 4.1. Summary of positive pre-modern characteristics.

Western pre-modern	Eastern pre-modern
Ordinary Based on experience (gradual evolution) Multifunctional space(s) Simple, direct, repetitive construction	
Durable, robust materials Identical room sizes Spatial generosity Structural redundancy Well-proportioned spaces 'Character', Permanence	Lightweight materials Non-permanent connections Storage space Standard modules Dimensional coordination Ephemeral mentality

Table 4.1 captures the positive characteristics of Western and Eastern prehistoric and pre-modern architecture. Contemporary buildings counterargument a wide variety of visual, physical and spatial variations that reflect different uses, travellers and cultures that have to deal with faster and larger demands that are not always common for the modification in the buildings.

Table 4.2. Technology development trajectory for each period.

Stage	Year	Description
Early stage	1949~1980	Wood, plastic, framed, fixed
Middle Stage	1981~2001	Mobile, adjustable, produced in units, fast assembly
Recent Stage	2002~2008	Multifunctional, electric motors, automatic sense control
Recent Stage	2009~2019	Kinetic, adaptive, additive manufacturing (3D printing)

Table 4.2 explains the changes and developments in the technology of shading devices. The study states that during the development period 1949–1980, the set of sun visors was a fixed type frame consists of wood or plastic. The study also configures that during the interim development period, i.e. 1981-2001, the building's shading devices were manufactured as mobile, adjustable and rapid assembly units. Moreover, it has been stated that most are manually adjusted are to achieve shade within the buildings. The manually adjustable magnetic clips do not immediately adjust to changes in sunlight, as the shading must be manually adjusted. The study further states that in the most recent development period between 2001 and

2008, the sun visor was a multifunctional mode using an electric motor and automatic induction control. One type of electric sunshade requires an external power source for the shading effect, which can be used to adjust the angle of the sunshade, resulting in low efficiency. To overcome this weakness, a sun-shading device was developed in recent time (2009-2019) through adaptive control of mass-production additive manufacturing to fill the gap in technical improvement.

4.2 The Current State of Research

Much of the work done in architectural discourse seems to involve a wide range of influences on the appearance of the buildings and their external and internal relationships. The depth of physical ornamentation was explored largely in the books such as ‘The Function of Decoration’ (Moussavi and Kubo, 2006) and ‘Ornament: The Politics of Architecture and Subjectivity’ (Picon, 2016). These works include a discussion of the quality of the materials and the influence of the atmosphere. In particular, the depths of the first use this as a grading method to discuss the relationship between building construction and influence as a continuum of continuity. However, they do not associate their viewing habits and architectural influences with environmental issues. Before that, philosophical perspectives in Bohme books’ ‘Atmosphere: essays on the new aesthetics’ provided a broader definition of beauty, including human comfort and the environment (Gernot Böhme, 1995).

Exterior shading structures, such as those of “Brisé-Soleil” from Le Corbusier’s solar shading strategy, have been widely discussed in the co-industry text on expression and function of climate, this has been discussed by many other scholars such as Benton (2012), Curtis and Secs (1978), Kamal and Arabia (2013), Lewis and Lewis (2018), Leatherbarrow (2013).

Architect Andreas Ruby (2004), in his book ‘R and Sie...Architects: Spoiled Climate’, presents several examples that call into question the concept of environmental design. Although this book consisted of deep-scale projects, Ruby does not include a detailed discussion of the depths of interaction between multi-layered interactions with the environments. Well-established and old buildings have a strong relationship between energy and architecture. The seminal work ‘The Architecture of the Well-Tempered Environment’ (Banham, 1984) sums up the impact of energy on architectural forms of the buildings and its connection with the environment. Leatherbarrow, in his writing, Architecture's Unscripted Performance (Buntrock, 2006) questions the concept of “equipment paradigm” asking whether a building’s physical properties influence its climatic properties, which reduces its dependence on HVAC systems. In the works ‘Performance-Oriented Architecture’ (Hensel, 2013) and ‘Grounds and Envelope’ (Hensel and Turko, 2015), Architect Michael Hensel discussed the relationship between architecture and the environment. Despite the supports, the design of multilayer envelopes to achieve this goal, there was no clear summary or systematic study of the multilayer shading concept in this context.

Victor and Aladár Olgyay (1951, 1957, 1963) carried out broad research on external shading configurations. The study goes beyond functional issues, including aesthetic and climatic factors, which are related to the objectives of this study. Their works are the foundation for project-based research in this field. In summary, the role of spatially defined boundaries in the relationship between internal and external discourse and the 3D structure of architecture is discreetly accepted as part of the architectural discussion. Nevertheless, it is not clear how these two aspects are combined with a multi-layered structural change to connect building and the environment. In part, this is because the relationship between them mediates deep skin transformation structures and has not yet been recognised. The purpose of studying multilayer leather, especially Brise Soleil Le Corbusier and other exterior sunshade structures is to fill this gap and discuss the building’s climate and atmospheric performance concerning working in-depth within these areas. In this respect, this research extends the hypothetical results by developing a concept of dual-layer shading system associated with innovative patterns applications.

4.3 Building Envelopes

The building envelope is the dominant design in most of the building subsystems such as structural, mechanical assemblies and field frames. It has to fulfil many important functions and is an important factor in the energy consumption of a building. Although the facades and roofs are exposed to different climatic conditions, they have very similar functions and are therefore sometimes difficult to distinguish. For this discussion, the two areas are connected in the general structure of terminology that is, in the outer skin (see Figure 4.8 and Figure 4.9). These features include:

• Lighting	• Gain in energy	• Ventilation
• Protection from fire	• Protection from humidity	• Protection from noise

• Insulation against cold and heat	• Prevention of mechanical damage	• Protection from wind
• Security and safety	• Protection from sun	• Transparency and Visual contact
• Protection from Glare	• Visual protection	

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Figure 4.8 Overall building system (Schittich, 2006).

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Figure 4.9 Building envelope parameters (Schittich, 2006).

4.4 Adaptive façades: background and characteristics

The utilisation of sunlight within houses may lead to substantial savings of electrical energy consumption when creating an excellent quality in a house environment. The huge benefits regarding efficiency in addition to reduced absenteeism associated with the environment of workers in all probability meet or exceed the strength savings. More strength savings often realise in the season in interior warmth profits caused by electric lights making an equivalent decrease in strength consumption. The technique of active creating envelope pieces in addition to systems highlights the potential for the excellent quality piece of work and also energy-saving solutions. Inventive daylighting systems focus on improve brightness quantities, also help to maintain direct sunlight and cutting glare (Cheng et al., 2013; Yu and Su, 2015). Predictive control algorithms are useful for maximising the functioning performance of HVAC devices which lead to the minimisation of energy demand such as heating and cooling loads while maintaining thermal comfort (Al-Tamimi and Fadzil, 2011; Heusler and Kadija, 2018).

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Figure 4.10 Overview of characterisation concepts for envelope adaptivity. Adapted from (Loonen et al., 2015).

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Figure 4.11 Schematic role of adaptive façade. Adapted from (Loonen et al., 2015).

Shading devices can be versatile to prevent direct sunlight and solar gains throughout the summertime, to maximise solar gains and sunlight during the wintertime, and to control direct sunlight by controlling sunlight without exposing it during the sunny and cloudy days. Controlling people over a mobile scanning device is unreliable and, when optimised, can result in constant passenger interference. In modern offices, there is an obvious need for efficient automation systems, especially high-spiral systems, atrium systems and curtain walls (Athienitis and Tzempelikos, 2002).

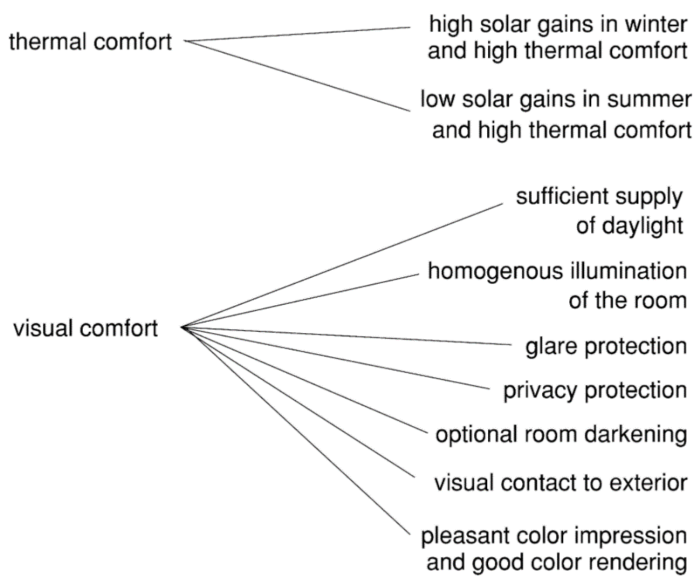

Figure 4.12 Daylighting and thermal requirements for sun-shading systems (Kuhn et al., 2001).

Therefore, new shading devices should be designed for the further development of energy reduction and shading devices using automated detection controls such as multifunctional and composite shading. When an existing sunshade design can integrate light-sensitive heat collectors, light transducers or automatic solar-powered sunshades, it responds effectively to environmental and climate changes, preventing sunlight from entering the room and reducing the burden on air conditioning. It is also necessary to solve problems of energy consumption and increase the competitiveness of the construction industry.

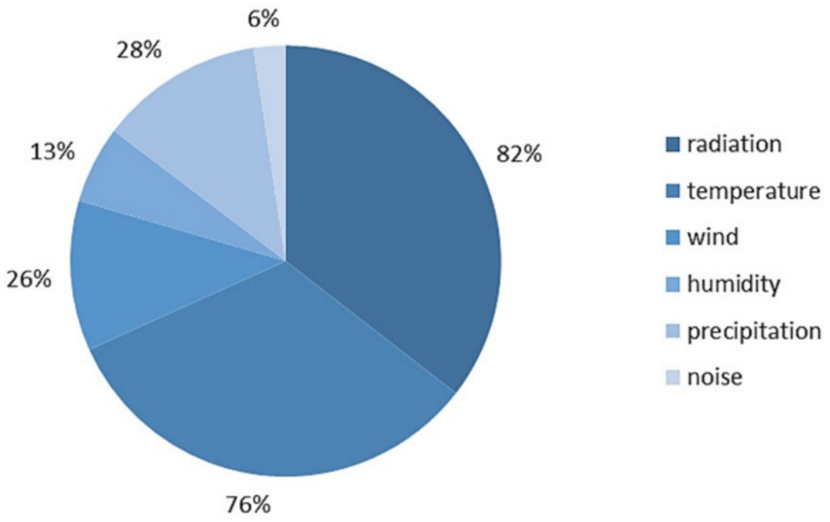

Figure 4.13 Global distribution of external factors (Aelenei et al., 2016).

For analysing the results of the proposed study, two different analyses were performed in 130 buildings. The purpose of the first analysis was to determine the distribution of external factors in each building, regardless of type or climate. As shown in Figure 4.13, the reason for using adaptive height or facade elements is mainly related to sunlight and outside temperature. Then, further analysis of the study could determine the ratio of wind to precipitation that it is more or less equal, followed by 13% humidity. The last distribution within the buildings is noise that causes 6% of the distribution.

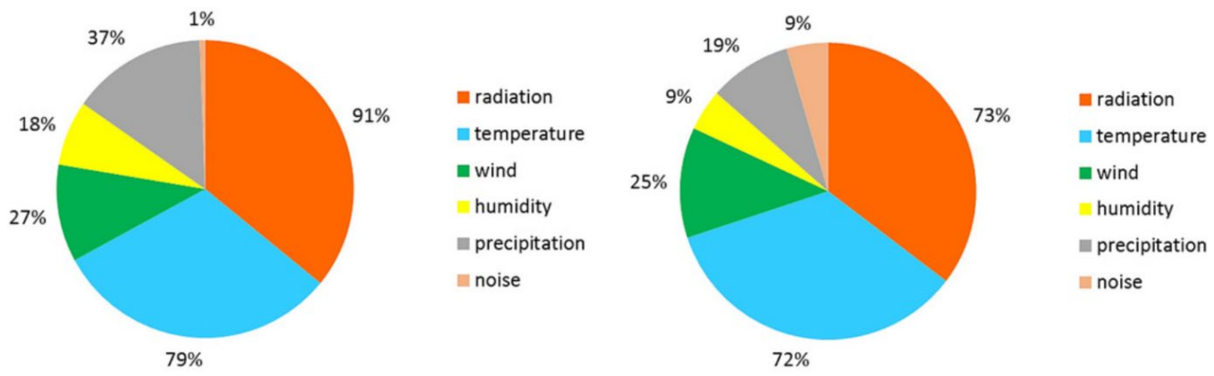

Figure 4.14 Distribution according to building type (left) residential; (right) non-residential (Aelenei et al., 2016).

The second type of analysis was to determine whether the external factors are distributed under different pressures when organised by building type or climate. To this end, the buildings are divided into two categories between residential (51%), and non-residential (49%) and the classification is recalculated very often. As shown in Figure 4.14, the comparison of the external factor classes in residential buildings shows the adaptability associated with solar radiation. External factors, such as humidity and precipitation, are also higher because there are many opaque envelope areas in the residential buildings, it often affects moisture condensation and collapses.

4.4.1 Automatically Controlled (Dynamic) Shading Systems

Dynamic shading devices adopt the automatic control mode as a key feature to respond to the environment by incorporating intelligent technologies (Giovannini et al., 2015). The term dynamic refers to a continual change process driven by variable stimuli, such as light and heat, in shading design. Dynamic shading systems can reconfigure their elements according to the sun's movement (Velikov and Thün, 2013) by dint of transformative elements that change over a specified time through the influences between forces and motions (Orzel, 2014). These systems can change under any external condition to provide interior comfort (Wigginton and Harris, 2013). However, active dynamic shading completely relies on automation to perform these responsive movements based on defined rules (Karanouh and Kerber, 2015; Loonen et al., 2013); thus, their application involves three components: the sensor network for obtaining data, the controller for determining a suitable action and several mechanical actuators (Konstantoglou and Tsangrassoulis, 2016; Al-Obaidi et al., 2017a). The role of the control system (sensors and controller) in the dynamic process is to receive environmental data, and then manage and modulate the orders being sent as signals to the actuators to perform the designed movements (Mughal, 2016). Undoubtedly, the design of a dynamic shading system requires a multidisciplinary field (Ferschin et al., 2015), including mechanical, electrical and software engineering (Dorf and Bishop, 2011), in addition to architecture, which concerns the design of the shading skin, its geometric shape, potential configurations and movements in a favour of a comfortable indoor environment. The study found that the complexity of a motion layout plays a key role in identifying different models of dynamic mechanical shading systems. Thus, the models were easily divided into two main groups based on the sophistication of their kinetic design: (1) conventional dynamic shading models with a simple motion design, such as venetian blinds, roller shades and louvres; and (2) kinetic dynamic shading systems with more innovative models and complex motion patterns, such as parametric geometries, foldable origamis and other models. Their performance and impact on energy and the built environment are further discussed in two sections.

Table 4.3 Criteria for defining simple and complex shading devices based on geometric and motion parameters. (Source: Author).

Parameters of geometric and kinetic complexity of dynamic shading devices									
Study	**Model**	**Units**	**Moveable elements per unit**	**Motion type**	**Movement number per unit**	**Motion degree**	**Formulation strategy**	**Motion typology**	**Degree of freedom (rotation)**
Simple shading models									
Tzempelikos and Athienitis, Skarning et al.	Roller shade	Single unit	Single element	Translation	Single movement	2D	One piece	–	–
Nielsen et al., Yun et al., Bunning and Crawford	**Venetian blinds**	**Multiple units**	**Single element/ unit**	**Rotation**	**Single movement/ unit**	**3D**	**Horizontal replication**	**Swivel**	**(0°–90°), (0°–30°), (0°–25°)**
Hammad and Abu-Hijleh, Konstantoglou et al., Sjarifudin and Justina, Grobman et al.	Louvres	Multiple units	Single element/ unit	Rotation	Single movement/ unit	3D	Horizontal replication	Swivel	(−80°–80°), (0°–90°), (0°–75°), (−45°–45°)
Priatman et al.	**Venetian blinds**	**Multiple units**	**Single element/ unit**	**Rotation**	**Single element/ unit**	**3D**	**Vertical replication**	**Swivel**	**–90° - 90°**
Complex shading models									
Kensek and Hansanuwat	**Folding panels**	**Single unit**	**Multiple element/ unit**	**Translation Rotation**	**Multiple movements/ unit**	**3D**	**One piece**	**Folding**	–
Grobman and Yekutiel	Kinetic cladding	Multiple units	Multiple element/ unit	Translation Rotation	Multiple movements/ unit	2D	Grid-based	Swivel Expanding	–
Yekutiel and Grobman	**Kinetic cladding**	**Multiple units**	**Multiple element/ unit**	**Rotation**	**Multiple movements/ unit**	**3D**	**Grid-based**	**Revolving**	**360°**
Elghazi et al., Sabry et al., Kim et al.	Origami screens	Multiple units	Multiple element/ unit	Translation Rotation	Multiple movements/ unit	2D	Grid-based	Folding	–
Giovannini et al.	**Kinetic Mashrabiya**	**Single unit**	**Multiple element/ unit**	**Translation**	**Multiple movements/ unit**	**3D**	**One piece**	**Complex typology**	–
Ahmed et al.	Kinetic device	Single unit	Multiple element/ unit	Translation Rotation	Multiple movements/ unit	3D	One piece	Complex typology	–
Mahmoud and Elghazi	**Kinetic panels**	**Multiple units**	**Single element/ unit**	**Translation Rotation**	**Single movement/ unit**	**2D 3D**	**Grid-based**	**Sliding Flap**	**– 30° - 165°**
Wagdy et al.	Solar screens	Multiple units	Single element/ unit	Rotation	Single movement/ unit	3D	Grid-based	Swivel	-25°– 25°

Table 4.4 Related papers with climate zones and passive cooling strategies by authors. (Source: Author).

Articles	Koppen climate zones	Passive cooling strategies			
		Shading	Glazing type	Glazing size	Vent
(Ahmed & Wongpanyathaworn, 2012)	Cfa				•
(Appelfeld, McNeil, Sr Svendsen, 2012)	Cfb/Csa/Dfb	•			
(Assem & Al-Mumin, 2010)	BWh	•	•		
(Aste, Compostella, Sr Mazzon, 2012)	Cfa	•	•		
(Bahaj, James, Sr Jentsch, 2008)	BWh	•	•		
(Baldinelli, 2009)	Csa	•		•	
(Bellia, De Falco, Sr Minichiello, 2013)	Csa/Cfa	•		•	
(Ben-David Sr Waring, 2016)	Aw/BWh/BWk/BSk/Csa/Cfa				•
(Chiesa Sr Grosso, 2015)	Cfa/BSh/Csa/BWh/BSk				•
(Eskin 8(Turkmen, 2008)	Dsa/Csa	•	•		
(Ezzeldin Sr Rees, 2013)	BWh				•
(Fathom', Chaiwiwatworakul, Sr Mettanant, 2016)	Aw	•			
(Favoino, Overend, Sr Jin, 2015)	Csa		•		
(Ferrari SrZanotto, 2012)	Cfa/Csa	•			•
(Geros, 1999)	Csa				•
(Goia, 2016)	Cfb/Csa			•	
(Hammad Sr Abu-Hijleh, 2010)	BWh	•			
(Hamza, 2008)	BWh		•		
(Heeetal., 2015)	Af/Cfa		•		
(Huang Sr Niu, 2015)	Cwa		•		
(Hwang Sr Shu, 2011)	Am	•	•	•	
(Ji, Lomas, Sr Cook, 2009)	Cfa				•
(Kolokotroni Sr Aronis, 1999)	Cfa				•
(Lau, Salleh, Lim, Sr Sulaiman, 2016)	Af	•	•		
(Lee, Jung, Park, Lee, Sr Yoon, 2013)	Af/Cfa			•	
(Manzan, 2014)	Cfa/Csa	•	•		
(Chaiwiwatworakul et al., 2012)	Aw		•	•	
(Moretti Sr Belloni, 2015)	Cfa		•		
(Pino, Bustamante, Escobar, Sr Encinas, 2012)	Csb	•	•	•	
(Roach, Bruno, Sr Belusko, 2013)	Csa				•
(Samaan, Farag, Sr Khalil, 2016)	BWh	•	•	•	•
(Schulze Sr Eicker, 2013)	Csa/Cfa/Cfb	•		•	•
(Sherif, El-Zafarany, Sr Arafa, 2012)	BWh	•			
(Solgi, Fayaz, &i Kari, 2016)	BWh				•
(Stazi, Marinelli, Di Perna, & Munafo, 2014)	Cfa	•			
(Tsikaloudaki, Laskos, Theodosiou, & Bikas, 2012)	Csa	•			
(Wan Nazi, Wang, Sr Roskilly, 2015)	Af		•		
(Wan Nazi, Royapoor, Wang, Roskilly, 2017)	Af		•		
(Wang &i Greenberg, 2015)	Cfa				•
(Yang & Li, 2008)	Cwa				•
(Yoon, Kim, Lee, 2014)	Cwa	•	•		

Conventional dynamic systems are characterised by their simple kinetic design. Their geometric shapes may include one moveable element, such as a roller shade with a single planar motion (2D shading system) or one device with several identical elements, such as blinds, louvre blades or fins with axial rotation (3D shading system). Tzempelikos and Athienitis (2007) investigated the energy performance of a dynamic roller shade in an office building in Canada. A simulation-based analysis was conducted with variable solar transmittance, electric lighting control and 30% WWR. An automatic strategy opens the shade at incident radiation of less than 20 W/m2. The results showed that automatic control reduced annual cooling energy by 50% and increased lighting demands. However, the total annual energy decreased by 12% compared with that of a bare window. Nielsen et al. (2011) assessed the potential of automated fully retractable venetian blinds on office buildings in Denmark through simulation. Lighting, cooling and heating demands were quantified under three cases (without shading, with fixed shading and with automatic shading) at different orientations and window heights. Automated solar shades on the south for a 1.5m window height achieved the best situation with a total energy demand of 46 kWh/m2/year, whereas the best daylight performance against fixed shading provided a 2% daylight factor and 200 lx at a depth of 4m with a window height of 2 meters. Konstantoglou et al. (2013) optimised a control strategy for dynamic louvres in an office building in Greece. Different slat angles were proposed based on daylight adequacy, glare reduction and outside view. Lighting, heating and cooling energy consumptions were investigated for a set of slat angles with several WWRs. The study showed that solar heat gain and cooling loads significantly decreased, whereas heating demands slightly increased. The proposed strategy reduced lighting energy by 25% compared with static slats. Yun et al. (2014) conducted a simulation and field study to evaluate the visual comfort and energy performance of automated venetian blinds, as shown in Fig. 13. Three orientations, ten lighting systems and shading control strategies were tested in an office in South Korea. The findings indicated that shading and lighting controls considerably reduced lighting and cooling energy and prevented glare. Priatman et al. (2015) evaluated the temperature and illuminance performance of solar-powered automated fins for offices in Indonesia. The study performed a real experiment with a feedback loop protocol that maintained 300 lx indoor. Fully opaque and perforated fins were tested. The blades successfully rotated under electronic control and solar energy. The results showed that a temperature difference of ±3 °C was obtained whilst the perforated blades achieved uniform daylight distribution.

4.4.2 Current Solutions for Adaptation

Concerning to the adaption or adaptability of facades it has been identified from the research of Lin et al., (2019) in some studies that are related to shading devices control have proposed and discussed the methods and procedure of control that deliberate some numerous determinations, such as cooling energy, lighting indoor, glare, and illuminance. Moreover, from the existing researches, related to the adaptive facades it has been identified that their primary emphasis is on sustaining a single condition that is upholding satisfactory and adequate amount of solar radiation or temperature. Furthermore, from the research of Gilani et al. (2017), it has been identified that an algorithm concerning to external Venetian blinds for adaptive control in facades has been anticipated which discourses diverse goals after and during work hours, which are converging on energy conservation after work hours and on visual comfort during work hours. However, the research of Marco Manzan and Alberto Clarich has discussed and anticipated an algorithm which is related to the day lightning and energy optimization along with the adaptability facades related to the device of external shading with the agenda of minimising blinds activation hours and primary energy consumption. Furthermore, the research of Sabine Hoffmann et al. discuss that the utilization of simulation tools such as Window, Energy Plus, and Radiance, are evaluating the recitals of numerous systems of exterior coplanar shade in the context of whether or not energy-efficiency, glare, and daylight goals are contented, and explanations have been discussing the significance of automation shade that includes glare control along with the adaptable façades. Therefore, to copiously take benefit from the shading device which is external, and capable of conserving lightning and cooling energy along with the improving the indoor comfort. In addition, it is essential to manage the shade's operation in such a way that satisfies several goals. In previous researches, roller blinds or Venetian blinds were primarily considered as the types of shading devices that are movable in nature. Nevertheless, in several current buildings, the shades are utilized as a feature that is designing the building envelope, such design feature comes in numerous employ complex operating structures and geometrical shapes. Hence, a method of controlling and evaluating a shading device anticipating only the shapes and kinds of roller blinds or traditional Venetian blinds which might prove inadequate in its applicability (Choi et al., 2017).

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Figure 4.15 South-west facing facade of a commercial office building in San Jose, California, where sky conditions are typically clear. Image credit Prof. Charles Benton.

Figure 4.15 demonstrates the common consequence of a "transparent" frontage made mainly opaque by its limiting daylight transmission, occupants, and views to the outdoors. The south-west facing frontage of San Jose California commercial office building, where sky situations are characteristically clear. Adaptive façades – optimization, simulation, and modelling.

Moreover, adhering to the design practices of contemporary daylighting and different adaptive patterns of climate and weather, which errand very glazed "transparent" frontages, develop in the form of heating-dominated climates, relatively cool, of the northern side of Europe. It has been analysed from the northern side of Europe that the low demand for air conditioning and predominantly overcast skies. It has been investigated that lack of adequate and effective shading, even in the United States the climates with substantial sun hours, frontage gains the solar heat which ultimately leads to substantial loads of cooling that are conservatively counterpoised by the air condition use. Nonetheless, the location of maximum existing "transparent" construction, and the mainstream of 21st Century and future growth will be in much furnace climates. It has been investigated that the dissemination of contemporary responsive and pattern such as "transparent" and its architectural design features to these sites, deprived of any recompense for the climate and weather condition. In addition, it will have substantial negative adverse possessions on outcomes of carbon and kinetic energy due to the air conditioning level which is desired to make such buildings operable. In order to make such building operable, the conditioning level is combined with usually the greater intensity of carbon with the supply of electricity in several regions.

4.4.3 Design for the Next Century

Figure 4.16 is the operation example outcome for a “transparent” façade in California, assimilating a glazed envelope which is in high transparency delivers daylight design with the incorporation of effective control of solar which helps in enabling low and passive kinetic energy cooling which helps in the provision not only in the day lightning assistances but also with the greater reliability associated with its operation and responsiveness. Such association could be attained in such a way that the passive survivability throughout possible intermissions to the grid electricity along with the greater possible for response demand to accomplish electric load time-dependent. For instance, floor plate of the 11-story, 22,600 m2 Canberra, Australia office tower which is side ignited on three to four sides by a glazed frontage of floor-to-ceiling curtain wall “spectrally selective Low-E facade glazing VLT 62%, SHGC 0.28, u-value 1.64 W/m2K”. Furthermore, the frontage glazing is sheltered by exterior horizontal wood fixed to louvre screen. Moreover, it has been analysed that the engineers are helping the provision of satisfactory solar control which helps in enabling the passive and low-energy application in order to deliver the cooling strategies as an alternative option that helps in emphasizing the air HVAC. In addition, the louvres blocking angle is estimated to the solar gain limit peak to 61 W/m2. However, this was necessary to be attained in order to control the low and high-temperature efficiency under air floor system which is paired with night-flush cooling and natural ventilation which could be beneficial in utilizing the peak cooling demands. Therefore, analysis and examination have been done in automation way with the help of proprietary engineering software in order to investigate and study several strategies of external shading vertical and horizontal along with the combination of glazing using Canberra climate data. Hence, the glare control has been provided to inhabitants manually by operating interior roller shades which were around VLT 6-8%.

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Figure 4.16 Example operational outcome for a “transparent” facade located in San Jose, California, at different times of the year. Image credit Prof. Charles Benton.

Figure 4.17 is illustrating the solar control exterior of the New Acton Nishi in Canberra Australia office building. The external screen is intended to bound peak and extreme radiations of solar to 61 W/m2, which helps in allowing the low-energy environmental application in order to control strategies. However, the automated night, natural ventilation, flush cooling of uncovered real ventilation and thermal mass via the underfloor air distribution system.

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Figure 4.17 Exterior solar control screen of the New Acton Nishi office building in Canberra Australia. Image credit Carl Drury.

Further added to the discussion, renewable energy such as kinetic and other excluding is engendered on-site in 2015 the building caused in a restrained and openly revealed through the “Australian Government’s Commercial Building Disclosure (CBD) program” in which consumption of annual kinetic energy has been measured, which was around 1662,000 kWh (73 kWh/m2-year), and an carbon emission intensity annual which is estimated around 45 kgCO2-e/m2. Thus, it makes it one of the greatest efficient resource of Australia commercial buildings.

4.5 Chapter Summary

As investigated early in this Chapter, the notion of adaptability, in general, is not new; historically, it has grown and transformed in many centuries and societies around the world, and evidently is heavily influenced by the site context and its climate. This means that adaptability is a fluid concept; conditional under a broad range of physical and social factors, and adaptable shading devices are no exception.

The literature survey shows that there is great potential for further reducing energy use via the kinetic shading systems. Likewise, novel methods of saving and producing energy will influence how such systems are designed. The potential of these façades is that, starting with a task of solar control, to improve on the energy consumption and daylight distribution, which is difficult with static envelopes, but also perform a culturally expressive role, such as promoting identity and regional distinctiveness.

Undeniably, the increasing demand for high-performance of adaptable shading systems will push the advancement of the external facades from static to multi-layered dynamic solutions. In practice, diverse control functions and adjusting thermal and visual comfort will also enrich the conventional functions of building facades. Hence, dynamic facades have become an increasingly valuable and the invention of a novel, cost-effective materials and components will play a significant role.

To advance the topic of the kinetic shading devices with a purpose of creating truly sustainable architecture, designing must be resourceful, responsible and reasonable. Thus, a high level of technological and creative competence is important. Apart from the novel aesthetics, the immense potential of the shading devices must be achieved from both a practical and environmental point of view to foster the innovations of sustainable architecture that looks towards the future. Such functional and environmental ability is further discoursed in Chapter 7.

CHAPTER 5: LANGUAGE OF ARCHITECTURAL FORMS – SHAPE GRAMMARS

5.1 Noam Chomsky's Syntactic Structures

Noam Chomsky, a linguist who is Cambridge based and a faculty member of MIT, published the '*Syntactic Structures'* (Chomsky, 1957) known as the world languages and the grammars exploration in which the existence was claimed of what is known as the universal grammar. The Syntactic Structures was a book of just 118 short pages, which began the modern avalanche of the "cognitive revolution" and inspired many philosophers, psychologists and neuroscientists over the last eighty years (Benros, 2018; Benrós et al., 2012; Knight, 1998; Knight and Stiny, 2001).

In the seventeenth century, the cognitive perspective was first coined, which then assigned modern linguistics in the fields of human biology and psychology. Children grow into adults with different systems languages, determined by their raising environments, for instance, Japanese if raised in Tokyo and some variety of English if raised in a village of Cornwall.

The primary aim of an analysis of a language *L* is to divide the sequences of its grammar, the L's sentences, from the ungrammatical strings which do not belong to the sentences. Thus, an *L*'s grammar will be a device which produces only *L*'s grammatical strings and will ignore the ungrammatical ones. Chomsky proposed such grammars able to create sentences of any language by mean of exploration. In doing so, he suggested that linguistics must concern with the matter of verifying the elementary structures of productive grammars.

He perceived that "*the grammar is materially simplified when we add a transformational level since it is now necessary to provide phrase structure directly only for kernel sentences*". Always concerned with the precise formulation of the grammar, Chomsky emphasised that the analysis required arrangement of the transformational rules and a discrepancy between the mandatory and optional rules. As a new grammar form, an example to determine the fundamental analysis, as follows:

(i) Sentence → NP + VP

(ii) Verb → hit, took, etc.

(iii) N → man, ball, etc.

(iv) T → the

(v) VP →Verb + NP

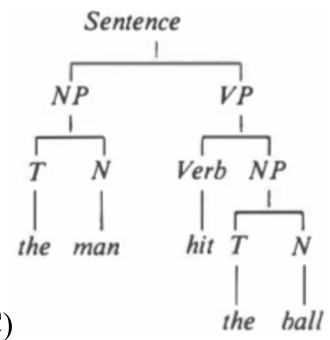
(vi) NP → T + N

Presume that each rule X → Y of (A) is an instruction to rewrite X as Y. Here the sentence (B) is a derivation of the sentence *"the man hit the ball",* where the rules of the "grammar" (A) (in numbers) are used to build a new sentence from the previous line.

Sentence	
NP + VP	(i)
T + N + VP	(ii)
T + N + Verb + NP	(iii)
the + N + Verb + NP	(iv)
the + man + Verb + NP	(v)
the + man + hit + NP	(vi)
the + man + hit + T + N	(ii)
the + man + hit + the + N	(iv)
the + man + hit + the + ball	(v)

Thus, the (B) second line is formed by the rewriting of the first line such as the sentences of NP + VP according to the rule (i) of (A); further, third line present is formed by the NP as T + N rewriting, third, the rewriting forms the line from the second related to the rule (ii) of (A), etc. Derivation B can be represented in several visual means by the diagram:

(C)



Chomsky argued that at higher (or newer) levels, an analysis might influence the lower morphological levels; therefore, the syntax work could keep going on, even with unresolved problems remained in the inquiry. This was a significant methodological revolution, and a claim of a novel scientific approach based on explicit, formal, generative accounts. Importantly, his technical innovation was to provoke many levels of interpretations, which formally act as the mechanism of transformational rules.

He presented the idea when observing the applied language words and rules to the small children, which they have learned to create sentences which were never heard before. This led him to the conclusion that innate grammar must be processed from birth. Universally, the grammar is pointing out towards the common grounds linking with several languages. Chomsky linguistic structure theory was innovative, but it could also be extended towards several disciplines such as art history, geometry and architecture, this can also be seen in the George Stiny works and his shape theories which will be discussed later in this chapter.

In Syntactic Structures, the linguistic structure theory was defined by the recognition of the key component of grammar and semantics: *"Syntax is the study of the principles and processes by which sentences are constructed in particular languages"*.

Here the set of rules might be considered, which allows for the words and sentences orderly arrangements: linguistic level is descriptive devices set that are used for constructing the grammars, although a language establishes a set of finite or infinite sentences. Here, the perception of Semantics connects to purpose, meaning or reasoning. There are two meanings that Semantics possess; one is philosophical and one in linguistic — namely 'the science of meaning in language'. To demonstrate this, let's examine the sentence:
"Pigs fly".

Grammatically, it has corrected syntax, though rationally and sensibly, it contains no semantic significance. The language of grammar is a tool that produces only grammatical strings. For operative grammar, one of the requirements is that it must be finite and is independent of meaning.

Unexpected emergences are a form provided by the author or grammar user. Unexpected shapes often require rules for defining fields to work. However, for some interesting design issues that people may want to anticipate how unexpected shapes and rules will be handled accordingly. Special rules for calculating unexpected shapes allow people to process the grammar of pre-processed grammar.

5.2 Languages of Architectural Form

5.2.1 Design Possibilities

The correlation between architectural design and mathematical narrative was established since Marcus Vitruvius Pollio De architectura, setting the first foundation for the geometrical abstraction and conceptualisation, upon which technical drawings became ‘measurable’ (Le Goff, 1964; Thoenes and Evers, 2003). Noticeably, following the treatise “De architectura” by Vitruvius, the French scholar Viollet-le-Duc (1814-1879) was the first to clarify that mediaeval building construction pursued both a set of rules to spatial dimensions and a system in which elements were arranged in succession (Ackerman, 2002). In fact, he verified that Gothic cathedrals were not the result of an empirically improvised building practice; actually, they were astonishing structures well-proportioned in every part, perceived in line with the fixed and constant rules of the revived aesthetics (Fossi, 2008).

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Figure 5.1 Left: Plate II from the book Gothic Architecture, Improved by Rules and Proportions by Batty Langley and Thomas Langley (1747). Right: rules for structural carpentry according to Chinese Yingzao Fashi architecture (Wang, 2015).

Specifically, ratios and proportions were calculated to replace the lengths identified by the reference points with numbers, for example, in Figure 5.1-left analysis of the geometrical composition for the columns of Westminster Abbey (Ackerman and Wittkower, 1951; Payne, 1994). What Viollet-le-Duc proved for Renaissance buildings was also true in the Oriental world. For example, Figure 5.1 right shows a module system of Chinese coding of rules used to assemble wooden structures, in which, the dimensions of the most important component are used for regulating the proportions of all other components (S. Li, 2003). This system enables every type of Yingzao Fashi architecture to be built through a compositions of the prefabricated components (Liu and Wu, 2015).

Algebra and its troubles, in the design possibilities universality, usually, obtain a lot. Possibilities of a vast number are then to be contained, does not have any architectural meanings, they might have possibilities, but their meanings are uninteresting or irrelevant (Sanabria et al., 1992). One of the most powerful generative introducing the grammatical combination ideas. It can be done if we specify or choose architectural vocabulary of element type definition that is instantiated only in certain combinations with different other elements. That is, in the type of definition, specify certain relations externally.

Here, the analogy with speech is close, and, the noun must be in English that must be instantiated in sentences in the combinations of certain kinds of other words, as given by the English grammar rules. Thus, not every string of words in the sentence must be of English: these strings are the ones that comply with the English grammar rules, which is further counted as sentences.

A simple and clear illustration of this kind is provided by Alberti's handling by piers, columns, arches and entablatures, as it is analysed by Rudolf Wittkower (1962) in his book ‘Buildings of Religion’, consistently, Alberti avoided the column and arch combination. When the columns were needed to be used, he did straight entablature was also given, while then the arches were introduced by him, they were made to rest on pillars by him without and with the set of half-columns against the decoration.

In Roman architecture, both forms of models were found by Alberti. Whereas the first motif at first is Greeks, the mediator role is played by the Romans, and the second motif is the Romans. The Greeks (first motif) is grounded on the column functional meanings, and the second one is based on the unity of the wall and cohesion. This latter point is explained: in the Colosseum, which may be the arched pillars that are interpreted as the pierced wall residues, having columns in half, which carry the entablature straight, placed as the ornaments against them. Therefore, in practice, the conception of Alberti’s regarding the columns is Greek essentially, while the arch conception is roman.

In the thoughts, biologically, similar ideas related to the ranges and restriction of the combinatorial possibly were formulated by the French naturalist and zoologist Cuvier. It was noted by Cuvier (2011) that each of the organs might take several forms, and when these forms exist with the other forms, a combinatorial universe is presented. Further, he argued that certain conditions must be met by the combinations and the combinations that meet the conditions are in nature exist.

In a language, the grammatical rules in the architectural form, just like the spoken language are specified in several formats. As employees, the simplest approach, for example, stated by the Pugin, is displaying several exemplars of innocent and correct practice. Very commonly, this technique by the architectural theorists can be widely employed from the present day to the Vitruvius.

Furthermore, a sophisticated approach is the statement of the perspective rules generalised as in the textbooks of elementary languages to shape grammars. The architectural renaissance theorists were found particularly of doing this. In ‘Four Books of Architecture’ (Palladio, 1997) which was the translation of the original book (see Figure 5.2), Palladio introduced the composition rules as following: and although new things and variety may please to everyone, yet it is ought not be done contrary to the art precepts, and contrary to which dictates reasons: where although one sees that ancient also varies, yet from the universal, they never departed and important art rules, as shall be present in my antiquities book.

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Figure 5.2 Palladian villas floor plans collected from (Gurlitt et al., 1922; Palladio, 1581; Palladio et al., 1715).

The regulatory book typically is set by the Palladio for the designs of a villa. On each side the rooms ought to be distributed of the hall and entry; and further, it is observed that the right one corresponds to the left ones, so the fabric would be same as compared to others. The right windows correspond to the left windows and those directly above them that are present below, and likewise, the doors directly ought to be over each other, and the void must be over another void, and solid is present above another solid and face each other so that standing at the one house end one might see to other, which affords both cool and beauty in summer beside the conveniences.

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Figure 5.3. Substitution of the alternative wall and entrance treatments for a square plan (after Gibbs's A Book of Architecture).

Occasionally, architectural theorist established demonstrated substitution and schemata in similar ways. For example, James Gibbs produces diagrams showing how entrance treatments and various walls for each other in circular and square pavilions is present. In his books of Encyclopaedia of Architecture (2014), by the J.C Loudon, the schema was taken as an open cube for a cottage, then it was showed that how various treatments exteriorly might be substituted and is appropriate to the status of owner's. Furthermore, Bernard Tschumi (Souza, 2011) programmatically employed the architectural substitution from the lexicon chosen within the gridded framework of the ten-meter cube in generating the pavilions set in Paris for Park of La Villette.

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Figure 5.4. Substitution of the alternative wall and entrance treatments for a circular plan (after Gibbs's A Book of Architecture).

In the era of information technology, from the architect’s perspective, computer-based design tools promote design processes to both the design knowledge and rule algorithm levels, unlocking new horizons for creative expression of design possibilities (Gu et al., 2018). However, one must not forget that, before the emergence of the modern terms, such as the parametric, generative, computational, and algorithmic design in architecture, the longstanding history of building disciplines, around the world, has always counted on the design language, often by means of precise order and rules. In this research, the connection between rule-based design and creativity for the pattern generation is based on the theories developed upon the Chomsky’s Formal Grammars by George Stiny and James Gips (1971), known as the Shape Grammars.

5.2.2 What are the Shape Grammars?

In the problem solving of the generalising design, three different syntheses of design models can be identified: case-based reasoning, decomposition and transformation. These are the models that are different from one another for the knowledge of design in their associated formalisms. These are not the cognitive models necessarily, although they can match to the different human approaches taken while producing the solutions for design, the correspondence has not been adequately tested. Among these modes, the distinction lies in the design knowledge representation rather than for specific design appropriateness or the designing phase (Lou Maher, 1990). The identification purpose for more than one model is done to identify the appropriate formalisms for the design knowledge representation.

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Figure 5.5. Three Models of Design Processes (Lou Maher, 1990).

Transformation is considered as a holistic approach, this is related to the case-based reasoning, it uses the general episodes rather than the specific ones, and this includes the decomposition. In the model of transformation (Figure 5.4), the knowledge of design is expressed as a set rule of transformation where the left-hand side rule is then replaced by the rule of the right-hand side. The application most commonly in the transformation model is manifested in the grammars. While using these models, the associated issues are related to the design description and its representation, having control in selecting the rule of transformation, and the applicable termination rules,

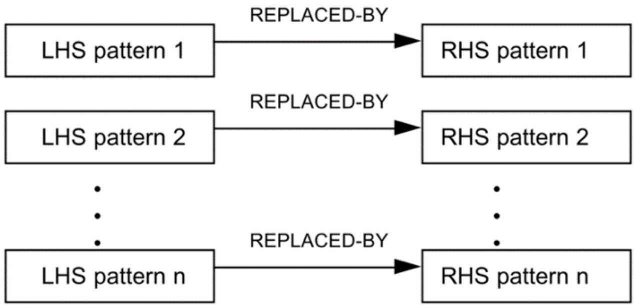

Figure 5.6. Maher's transformation model.

A theoretical approach is followed by the transformation model to design where the initial requirements of design are transformed into the solutions of design. The model of transformation begins the issues of approach regarding how the transformations occur. The grammars provide a formalism for the model of transformation, and here they are used in defining the model. A system of the general rule base shares several transformation model characteristics, where a subtle distinction is present. In the rule-based systems, a control system predefines determine the rules which must be executed few restrictions are present on the RHS and LHS rules. More explicitly, in a transformational model, in grammar, no control mechanisms explicitly are present, and rewrite rules are considered where the RHS is replaced by LHS. Commonly, grammar is associated with language rather than problem-solving or design. Understanding the principle and application of grammar in the design knowledge would need legal solutions for design in a language as it acts as a legal statement. By this, we can consider grammar as the formal design knowledge that is used to generate the solutions for the legal design, in order to check whether the solutions of design are legal or not. Here the legal is the term that is used in the broader context. This means that statement or the design solution conforms to the formal definition of language.

In particular, G = {N, T, P, S} is the grammar's formal definition, where N denotes the "non-terminal" symbols, "T" is the terminal symbols' set, "P" is the rewrite rules or the production's set, and S is the specific symbol known as "start" symbol. The highly successful and famous form of grammar utilised in design is known as "shape grammar". Shapes consists of lines and points are used in "Shape grammar". Its basic properties and formal definition have been applied and defined by Stiny and Gips (1978). The shape grammars' application to different architecture has demonstrated the shape grammars' ability to formally signify the knowledge of generative design and style of design capture. The specific applications including grammars, which signify the architecture of prairie houses of Frank Lloyd Wright, plans of Palladian villa plans, and Queen Ann–style communities.

The deliberations in utilising the grammar to signify knowledge of design synthesis include nonterminal and terminal symbols' definition and the productions' identification. The nonterminal and terminal symbols' definition is normally based on the shape's formal representation. The productions' identification gives the knowledge of the domain, where the productions signify transformations of design linked with a particular domain of design, such as the architecture of structural systems of a rigid frame, or style of design, for instance, prairie houses.

5.3 Shape Emergence and Ambiguity

The concept of emergence and the characteristics of emergence played an important role in some of the philosophical debates of the 20th century, especially in the 1920s and 1930s, when it provided an excellent metaphysical argument for the emergence of evolutionary theories (Jones, 1972). In the philosophy of mind, Brod's discussion of the psychosomatic problems of emergent characteristics is best known and often debated (Brett and Broad, 1928). He stressed that we must constantly remind ourselves of the ubiquitous nature of the world to show that a complex whole has a characteristic that an entire component cannot have insulation or other components. Different combinations are at the heart of many computer systems and retain the look of earlier characters. Knight (2003) emphasized the role of emergence in creative design and its unique manifestation in form grammar. Shape grammar creates an immediate shape - shapes not defined in the grammar. An emergent shape not only allows to calculate shape grammar but can also be used as an input for other calculations. Then differentiate between different forms of grammar: expected, possible, and unexpected.

Unexpected emergencies are a form provided by the author or grammar user. Unexpected shapes often require rules for defining fields to work. However, for some issues of interesting design that people may want to anticipate how unexpected shapes and rules will be handled accordingly. Special rules for calculating unexpected shapes allow people to process the grammar of pre-processed grammar.

The sounds and properties of the ingredients in a composition appear to give a sum of attributes that are not present. In other sciences, such as chemistry, comparable facts are unknown: the number of components at the time of separation differs from the sum produced by their combination. In this case, we may be confronted with an unknown law whose hidden characteristics make us fraudulent.

The emergent properties and emergence concepts have the main role in the philosophical debate in the 20th century, particularly during the 1930s and 1920s when emergent evolution's theories produced metaphysical controversy to a significant extent. In the "philosophy of mind", the discussion on the problems of mind-body concerning emergent characteristics is possibly discussed and known. It has been stressed that people must be continuously recalled of the emergence' ubiquitous nature, where "emergence" is utilised to specify the fact that a complicated whole has characteristics that the whole's constituents do not have separately or a combination. Nowadays, it is necessary to several computational systems that recall the emergence' hallmarks established much earlier. An emergence's role in innovative design and its distinct personification in "shape grammars" have been highlighted by many (Knight, 2003). "Shape grammars" produce evolving shapes-shapes not stated in the "shape grammar". The nascent shape is the input of computation and also the output of computation of shape grammar. Shape the emergence of different types in grammars are illustrious: unanticipated, anticipated, and possible. The emergent shapes, which are not predicted, are shapes not intended by the grammar's user and author. Normally, unpredicted shapes need rules' on-spot definitions to figure with them. But, for problems of some innovative design, it is probable to know what to do with shapes, which are not predicted and to the rules, which are defined before. Particular rules for calculating with unpredicted shapes permit for processes, which have earlier been managed grammars errors that must be dealt with in grammars.

"The characteristics and sounds of the composition and components elements produce in specific examples the qualities total not included by previous. The comparable facts are not known in different sciences, for example, chemistry: component elements' sum when alienated is not identified as their combination produced the sum. In these cases, they are possibly challenged with the law that is not known, whose unclear features strike them misleadingly."

The Bauhaus, who was a painter and a theorist, Kandinsky presented different ideas regarding the composition's nature in the previous books on art, which is not based on objective, Line and Point to Plane. Simultaneously, whereas Kandinsky was busy working on the art's new theory, a philosophy's school known as "British Emergentism" was flourishing. After George Henry and John Stuart's previous work, the British emergent or emergentists evolutionists-promoted a novel concept known as emergence. The classic, previous instance of emergence evolves from the discussion of Mills of chemical bonding wherein it has been observed that just summing the chemical components' properties do not predict or produce the combined components' effects. According to Lewes (1874), the word "emergence" to elucidate these chemical effects. Possibly, this is not accidental that Kandinsky selects a similarity from chemistry to elucidate identical emergent characteristics, which arise from the contrast of the art's basic components.

The emergence' concepts, which has become widespread, keeps its promises that established a year ago. The book "Emergence: from chaos to order" written by John Holland, states that emergence takes place when the parts' activities do not just total to provide the whole's activity. For emergency or development, the whole or entire is the addition of all parts". More often, provide instances, by different authors and Holland, of systems, which include emergence are self-organising, non-linear, and complex systems ranging from art colonies to economic systems. The observation of Holland that these systems' emergent behaviour provides the "feelings of more coming from little" and that "this feature likewise makes emergence or evolvement an almost paradoxical, mysterious phenomenon" recalls a sense of vague and undefined law of Kandinsky behind the emergence.

Moreover, unpredictability and novelty are the emergence's different constant themes. For the emergentists of twenty century, "Every real emergent presents the novelty into a world" (Jones, 1972). According to Holland, emergence goes hand-in-hand with "perpetual novelty", and for earlier writers, the evolving property is "unpredictable not just based on the available knowledge before its emergence, however, even based on the ideal information of the cosmos' state before its emergence". Surprise and unpredictability are still extensively linked with the emergence and possibly less acquainted are the concept of the emergence's hierarchical level.

Last century's British emergentists debated the emergence's existence level where "The high quality evolves from the existence of low level and has its foundation therein. However, it evolves from that place, and this is not owned by low level, however, comprises its possessor the existent's novel order with its behaviour's special law. Philosophers' succeeding generations reworked on that concept. Unexpectedly, this is reconsidered while discussing the emergence in Holland's book. The emergence's computational model of Holland depends on making the macro regulations, which elucidate the phenomena of emergent behaviour emerging from the low levels. It was written that these macro regulations applied to complicated phenomena, which are the original regulations' consequences; they are at a novel level. People gain the emergence's deeper understanding if they can increase their understanding of this notion of the definition".

Lewes, 19th century's philosopher expressed his views and hoped that one day the secretive "unseen process" of evolvement might be shown in the mathematical formula (1874, p. 370). The belief of Lewes may be contended by emergence's contemporary computational model. Certainly, the interest's recent wave in emergence is attributable partially to the computer scientists and mathematicians' work on computation, perhaps more to the fast computers' engineering to assist computation. The systems based on the rule from "cellular automata" to "shape grammars" may be utilised to understand and generate emergence or evolvement in its several senses. The behaviours or emergent objects may be produced by regulations that often apply to reconfigure, subtract or add components. The models of computation might be executed by hand or on computer. Rules might apply separately (several rules applying at the same time in the computation's every step), or regulations might apply serially. Several models of computation are formally equal, which might have identical generative power. But, one model might be easy to use, highly apt or give more understanding as compared to one more model, provided a specific task, and the tasks are different. Computation is utilised nowadays to analyse, visualise, and simulate the phenomena of the real world, and to explore, design, and invent imaginary or new phenomena.

Design means change; systems of design are formalisms that lodge the change's concept. CAD is the procedure, which uses mechanisms of computation to influence change. The way change is brought the methods of exploring the probable design. A predominantly related and enticing notion is emergence. The shapes are objects and alterations are spatial alterations. Functions on the shapes may be taken into account to be "geometrical transformations" (Krishnamurti and Stouffs, 1997). The part relation can be specified, whereby the shape's any part is the shape. The shapes identify the unlimited number of objects or shapes; each is associated with the original shape. The object's shape emerges under the relation of part, although these might not initially have been intended accordingly. The shapes of emergence become clear only when operated intrinsically and identify developing shapes need deciding the transformation under that shape similar to the original shape.

The concept that designs are the products of evolving spatial changes has been taken into account by different authors, such as by "Bridges (1991)" who informally explored the (presumed) role of computers in the design studio, and less casually by Oxman and Oxman and (1992) who, another time in the context of pedagogy, support that the precedents' understanding may be attained via transformational or spatial change's analysis that they allude as adaptation and refinement. The concept of learning spatial change—either formally or informally—is an old one (Galluzzi, 1987). Figure 1 shows the design for the church made by "Leonardo da Vinci". This is one of the instances of several designs that Leonardo developed with the octagon, which is not regular, a type with that was fascinated by him. This is a radiating plan based on a cross-shaped with substituting niches and chapels. The chapels of satellite attach diagonally meeting on the main space. An octagon rules a plan, and this is interesting to see irregular spaced grid used by Leonardo and the axial lines, which are progressively added to carve the developing octagon (however he was not constantly effective in an attempt).

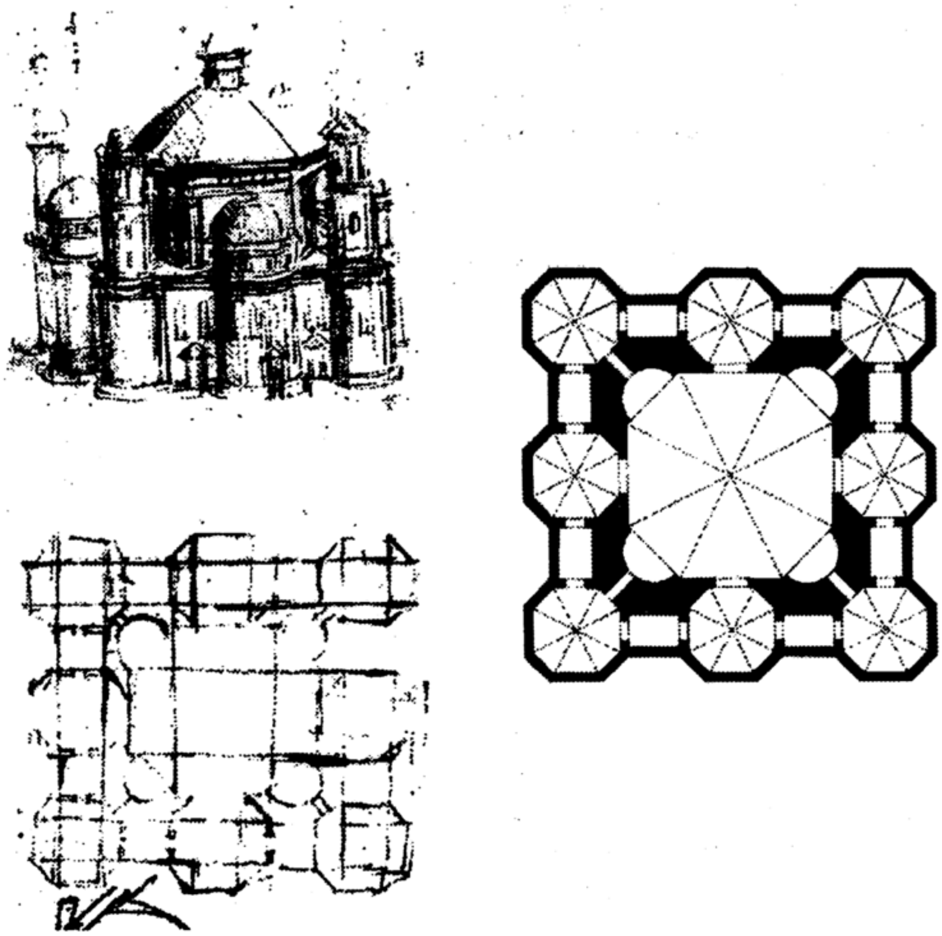

Figure 5.7. Leonardo de Vinci's design of a church (circa 1500).

Figure 5.8 shows how addition or superposition of the grid lines' two sets evolves an octagon. The plan proves the spatial change's three aspects, which shape this paper's subject matter.

Firstly, the plan's development via spatial change or transformation of the fundamental grid. Secondly, the octagons' emergence by separating the axial and gridline's specific parts. Thirdly, the presence of the continuousness of composition and overall structure.

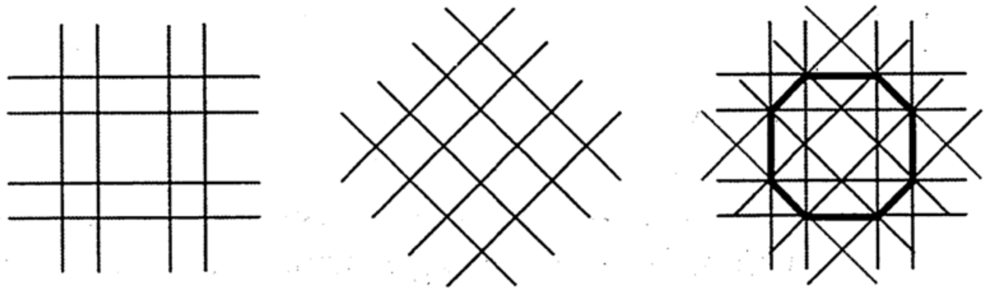

Figure 5.8. Emerging octagon by adding two sets of grid lines.

When designers work on the shapes, they do in a way, which is unique from the representations of computation for shapes. Repeatedly, this must do with the designing's process and with elucidations for decisions or choices of design. Differently, the shapes are structured to explain it. Normally, this structuring decomposes the shapes into different parts and the addition of these equal to complete the shape. The specific type of shape's decomposition corresponds to the topologies that are included under product and sum (Hocking and Young, 1988). The topologies for the shapes satisfy two extra conditions; firstly, both the empty shape and full shape are part of the topology and secondly, for the "shape x" that is linked with the provided shape, there is a small shape in a topology of that x is likewise a part. The topology's every element is the shape's part and, therefore, the addition of the topology's elements equals to a shape. The topologies for a shape indicate a method of parting the shapes into the fixed parts' collection. The shapes may have several topologies mentioned on it and for the shapes; two typologies are the "trivial topology" comprising the shapes and empty shapes, and the immeasurable topologies comprising the s parts. The fascinating typologies are those that divide the shapes somewhere amidst these extremes. Figure Figure 5.9 shows a topology and shape elucidated on it.

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Figure 5.9 Shape typology (Stiny, 2006).

5.3.1 Symbolic Process Models of Shape Emergence: 'Shape Grammar'

The most common notion in the theoretical basis of the models of computation using formalisms, for instance, evolutionary systems or neural networks is the unit's concept. But, to model emergence or evolvement in the domains of a figure, as per the Stiny (2001)'s theory, there must be a "break" or remove the unit's notion. When units are used to make shapes, units may be grouped to make limited parts. It is against the shape of ambiguity's concept that is suggested by Stiny. In the paper on "shape algebra" and Stiny in a book has demonstrated the mathematical viewpoint, which advocates the ambiguity's modelling, and gives the description for the capabilities to "see" various shapes in the drawings (Stiny, 1993). The shape grammars work as a significant contribution to an emergency' modelling. The symbolic model of Stiny, with its mathematical foundations, goes beyond shape recognition's computational model and interpretation by adjusting the emergent forms' generative propagation. That is, the work of Stiny identifies the transformational and generative aspects of emergence's cognition. In the design domain, Stiny was amongst the founders of the formal models' exploitation as the channel for modelling generation's role in an emergency. Shape grammars' mathematical foundations and formulation of the symbols as the transformational process give not just for the shape recognition's explications, however, likewise for the repetitive modelling of the emergence process.

The approach of Stiny to emergence is distinct, as it is leading in the grammar field, as it is apt to the design domains. Most of the computational and design's formal model cannot deal with the richness and complexity of the design's figurative nature in domains, for instance, graphic design, architecture, and art. Therefore, a method to "shape grammars" gives both mathematical elegance and precision of evocative ability whereas supporting complicated configurative elucidations. The formalism normally gives for the evolutionary, sequential representation and therefore is exclusively powerful in the modelling of a generation of spatial design. This evolutionary and sequential evocative perspective of the 'shape algebra' rules likewise makes it extremely pertinent to the shape emergence's explanation and modelling.

5.3.2 Shape Ambiguity: Understanding the Role of Shape in Design

The representations of shape, whether of the abstract or physical object concept, are susceptible to understanding. The process of reinterpretation (formulated again by drawing it again) and shape interpretation has been identified by different investigators as the foundation for interrelating with illustrations in design; the "seeing–moving–seeing" of Schon is only this procedure of reformulation and interpretation. The ambiguity of shape is taken into account by several investigators as the necessary condition and prerequisite for emergence. As the emergence of shape involves reformulation, ambiguity and integration, the processes are taken into account to be source for designers to "conceptualise" amid the process of design.

Therefore, emergence is not only the perceptual procedure but also a conceptual process. The ambiguity of shape is the main issue in the study on a reinterpretation of shape in design and shape ambiguities are intrinsic in the shapes' vision. Ambiguity is a condition; thus, the semantic and syntactic content of the shapes may be readable in different manners. From the psychological perspective, perception's principles in "Gestalt theory" elucidate how the mind may observe two diverse shapes from the sole visual imagery. From the perspective of a mathematician, the work of Stiny on the emergence of shape elucidates ambiguity due to the shapes' basic attributes. Shapes often do not have specific parts, and thus may be distributed into many sections in different ways. An individual always "see" something novel in shape: "The way a shape was developed and how this was divided into different dependent parts". Moreover, "Vagueness is somewhat to usage, and the innovation it takes makes the innovative design".

The neoclassical architect of France, designer and interior decorator, named Charles Percier won the “Rome Grand Prix”. His architecture for “A Building for Assembling the Academies” was extraordinary in several manners, particularly for its vagueness within the static grid. “David Van Zanten (1977)” elucidates this in the composition and history of “Beaux-Arts”.

By incorporating all spaces in the rectangular shapes and transforming them into the rectangular shapes within figures of the rectangle, Percier allowed his spaces to associate together evenly, to penetrate. The figures’ outer rectangle is always linked with the adjacent figures. When 3 figures of this type are made alongside, as they are longitudinally and laterally in the plan of Percier, it is not obvious whether an individual ought to read the consequent configuration as two rectangles, which are interlock with one another as 4 rectangles meeting at the midpoint of square, or because 4 rectangular shapes established around the main square’s sides. Percier, therefore, stuck his plan collectively and presented the play of vagueness via the modular grid’s use, of spaces in rectangular shapes, and many rectangles within the figure of the rectangle.

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Figure 5.10 Floor plan of Charles Percier’s assembling the academies (Stiny, 1989)

From the perspective of the designer, this elucidation tells the facts devoid of alternatives to particular devices of specific types. The design of Percier is the typical Greek cross’s variations that may be divided into several parts in several manners. If transformations or alterations are utilised to alter the rectangular shapes in the given list into identical ones, which might be united for the given purpose, after that the decompositions recommended by “Van Zanten” follow instantly. And other disintegrations are probable, also, concerning rectangular shapes or concerning other shapes

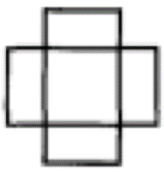
Ambiguity is used in design in different manners where it nurtures creativity and imaginations and motivates multi-layered response and expression. However, vagueness is noticeably absent from architecture when getting assistance from a computer, even in primary cases where architecture is provided along with drawings. The main reason for this is the computer drawings' structured nature, as Ivan (1975) described it.

To a significant extent, this has proved to be the computer drawings' usefulness is exactly their premeditated nature. The ordinary or common designer is not concerned with the structured material of drawing. Ink and pen, paper and pencil lack intrinsic structure and they make the papers dirty. The designers are concerned mainly with the figures as the emerging design's representation. The drawing's behaviour is based upon the geometric and topological structure established in the memory of computer due to operations of drawing. The drawings themselves have characteristics that do not depend on the object's properties described by it. From the perspective of the computer, there is a lack of ambiguity. Drawing every line has several descriptions, and one of the computers identifies the one decided as the drawing's structure is "established in the memory of the computer due to the operations of drawing". Ambiguity may contribute its complete part in "CAD" when the lines utilised by normal designers in the figures made with dull marks on the identifications are taken earnestly. In these type of efforts, success is based on the simple relations on the lines.

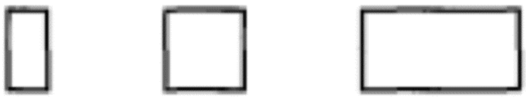
The cross is unwavering by the series of 8 maximum lines. This has 11 different rectangular shapes as "sub-shapes". Two of these are made by uniting a maximum number of lines in a cross, and the set's subset describes it. The remaining nine lines, although, have a maximum number of lines, which are not in a cross, however, which are entrenched in maximum lines. The cross includes different sub shapes, also, which might be utilised to decay it and some of the lines are renowned by weight of lines in the figures.

The shape's complete structure is provided by their all sub shapes. Some are partly arranged by the relation of sub-shape and the types of Boolean algebra. Identical shapes have an identical structure. The relation of sub-shape permits for shapes of the rectangle to be decayed in a way whatever. Working with shapes of rectangle goes forward communally with two types of operations to syndicate shapes, as well as the transformations. The operations of shapes are difference and sum. They relate, correspondingly, to erase and draw lines, and are willingly demarcated concerning the relation of sub-shape. The constructive approach, but, is required for the system; this is must comply with rules of reduction. The shape formed by illustrating two shapes collectively is their addition. The shapes are the addition of a square and a rectangle, its sub-shapes are the square or rectangles' sub shapes, state, the 3 shapes or syndicate the square and rectangles' sub shapes, as the shape does or syndicate the square and rectangles' sub shapes, as the shape does.

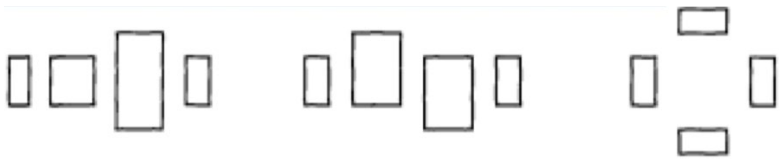
From the designer's point of view, this description merely states the facts and does so without recourse to special devices of any kind. Percier's design is a variation of the standard Greek cross



that can be decomposed into parts in many ways. If transformations are used to change the rectangles in this list



into similar ones that may be combined for this purpose, then the decompositions suggested by Van Zanten follow immediately. And other decompositions are possible, too, in terms of rectangles



or in terms of other shapes

Ambiguity has important uses in design where it fosters imagination and creativity and encourages multi-layered expression and response. But ambiguity is conspicuously absent from design when it is computer-aided, even in the basic case where designs are given in line drawings. The reason for this is the structured nature of computer drawings, as described by Ivan Sutherland (1975).

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Figure 5.11. Possible emergence (Knight, 2003).

5.3.2.1 Unanticipated Emergence

Shape grammar has a wide range of features, i.e. appearance, parameter setting, description, labels, weights, multiple charts and more. However, an interpreter has not been developed to support all of these features. Existing interpreters are limited to the purpose of their grammar. The syntax used as a creative design tool, i.e., grammar or composition of design, typically uses events and analogues during multiple transforms but does not use extensive mark-up or parameterisation. Simultaneous interpreters supporting this grammar, we call them synthetic interpreters that are subject to mutual restrictions (Li et al., 2004; Li, 2004). Because of these limitations, McKay et al. (McKay et al., 2012) observed, at least in part, that user interactions in these tools are often quite limited.

On the other hand, translators who support grammar or analytical translations tend to confront them. They use a variety of tags and parameters, but they do not appear or correspond to multiple conversions. In this case, the restrictions seem less obvious to the user. Taking an example from Queen Anne Flemming (1987). As stated by Stiny (1982), it is based on a series of observations and therefore, does not support it. He does not need that ability. He lost almost ordinary grammatical translators (Flemming 1987, 266).

In addition, he knows that design space is not otherwise limited, for example, the functions of edges include the fact that some edges form a rectangle below a selected representation and that it is not necessary to construct a rectangle. Chase (Chase, 2002) states that understanding the relationship between grammar and the design process requires further exploration of interactions as referred in Architectural Standards. Li built-in translator is part of a larger program that teaches this manual architectural style (A. I. Li, 2003), which gives us a concrete idea of the interaction between user and interpreter, although we clearly have the disadvantage that this translation fills in z, we have often benefited from some lessons relations between interpreters and translators.

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Figure 5.12. A shape typology (Stiny, 1993)

The definition and exploration of design spaces is a fundamental activity in generative design (Prats et al., 2006). As a result, the design space is a primary object for research intended to realise computational systems that support generative design (Aish and Woodbury, 2005). This paper presents a discussion on the relation between emergence in a generative system of design and the resulting design space. Intuitively, a relationship does exist, since the emergence in a generative process is likely to result in the generation of a broader range of designs, thereby expanding the boundaries of a design space. However, the extent to which this intuitive understanding is true remains to be seen. Here, an exploration of this issue is presented which is based on consideration of different approaches to generating designs within the same style. Three different methods of generating Islamic geometric patterns are investigated, and because the different methods generate designs in the same style, they provide a common ground from which to explore the relation between the use of emergence in a generative process, and the resulting design space. The aim of this exploration is to achieve a deeper understanding of the role of emergence in design generation and hence inform future development of computational systems intended to support generative design (Jowers et al., 2010).

The concept of emergence is not easy to define. For example, in complexity theory emergence "refers to the property of a collection of subunits that comes about through the interactions of the subunits and is not a property of any single subunit" (Flake, 1998). With respect to geometric design, emergence can be defined as the construction of a shape that is not explicitly represented or identified in the method used to construct it. In this mode, it has been suggested that emergence plays a key role in design generation and exploration, as discussed by Schön and Wiggins (1992), Gross (Gross, 2001) and Knight (2003). Consequently, it is of interest to support the recognition and use of emergence in computer-based representations of shape. However, the problem of supporting emergence is exacerbated by the fact that it has many different shapes.

Gross (Gross, 2001) identified three types of emergence that should be supported in computer representations of shape, these are:

- emergence that results from intersecting shapes
- emergence that results from alternative configurations of parts of shapes
- emergence that results from figure-ground reversal.

Knight (2003) argued that there is a distinction between emergence as process and emergence as a product that explores at length. Emergence as a process is characterised by emergent forms that are both recognised and used. For example, a foundational feature of the shape grammar formalism is that emergent shape is recognised and used in the process of generating designs (Stiny, 2006). Emergence as a product, on the other hand, is characterised by emergent forms that are recognised but are not used. For example, cellular automata are often cited as examples of emergence since they are defined by simple rules but give rise to complex forms (Flake, 1998).

5.4 Chapter Summary

Formal grammars have been studied for the last sixty years, starting with the concept of Chomsky and others (Chomsky, 1980, 1956; Lees and Chomsky, 1957). The most significant attribute of Chomsky's model is a system that encourages creative pursue. This concept explains the ability of a subject to produce an infinity of words and sentences, supplying unlimited use of finite means. Among the branches of Chomsky's theory, one that has obtained a special attention from both the computer science and design community is Shape Grammars concept (SGs), introduced by George and James Gips in early 1970s. Stiny's SGs provide a pragmatic tool that is able to replicate the process of given style and recreate the language consistently. Ultimately, this concept is based on the notion that buildings, since the Middle Ages, have got their own language and could be viewed as a form of symbolic calculation, as proved by Vitruvius and Viollet-le-Duc; that is, a sequence of operations done by algebra representation of the object being designed.

However, designers do not naturally build their language with such precision but with exploration, creativity, and culture; as such, their language grows and transforms. From a designer's perspective, shapes can be interpreted in many different ways from how they look. Unintentionally, such an interpretation is prohibited by current computer-aided design systems due to their enforced fixations.

A creative mind 'sees' different shapes to their origins drawn by another creator. Shape grammar process, by its nature, provides a capability to recognise emergent shapes and pose opportunities to create design innovative visuals systems in the conceptual stage of design. In other words, the two schemas of shapes, the original and the emergent, can coexist in the same system. Two types of shape emergence – anticipated and unanticipated emergence, were considered suitable for augmenting the innovative thinking of the system. By doing so, shape grammar process can eliminate the fixation created by the computer-based interpretation. A framework for such procedure, using constrains of shapes and rules analysed in Chapter 3, will be explained specifically in Chapter 6.

CHAPTER 6: KiSS - DESIGN FRAMEWORK FOR VIETNAMESE ADAPTIVE SHADING DEVICE SYSTEMS

6.1 Conceptual Framework and Shape Grammar Generation

This chapter presents the development of a design framework of a novel kinetic shading system (KiSS) for Vietnamese contemporary façade design, based on the parametric design strategies extracted from the theoretical research (Fig 6.1). It uses a multi-agent system with the goal of refining and partly automating the design process, conscious of both aesthetics and building energy performance.

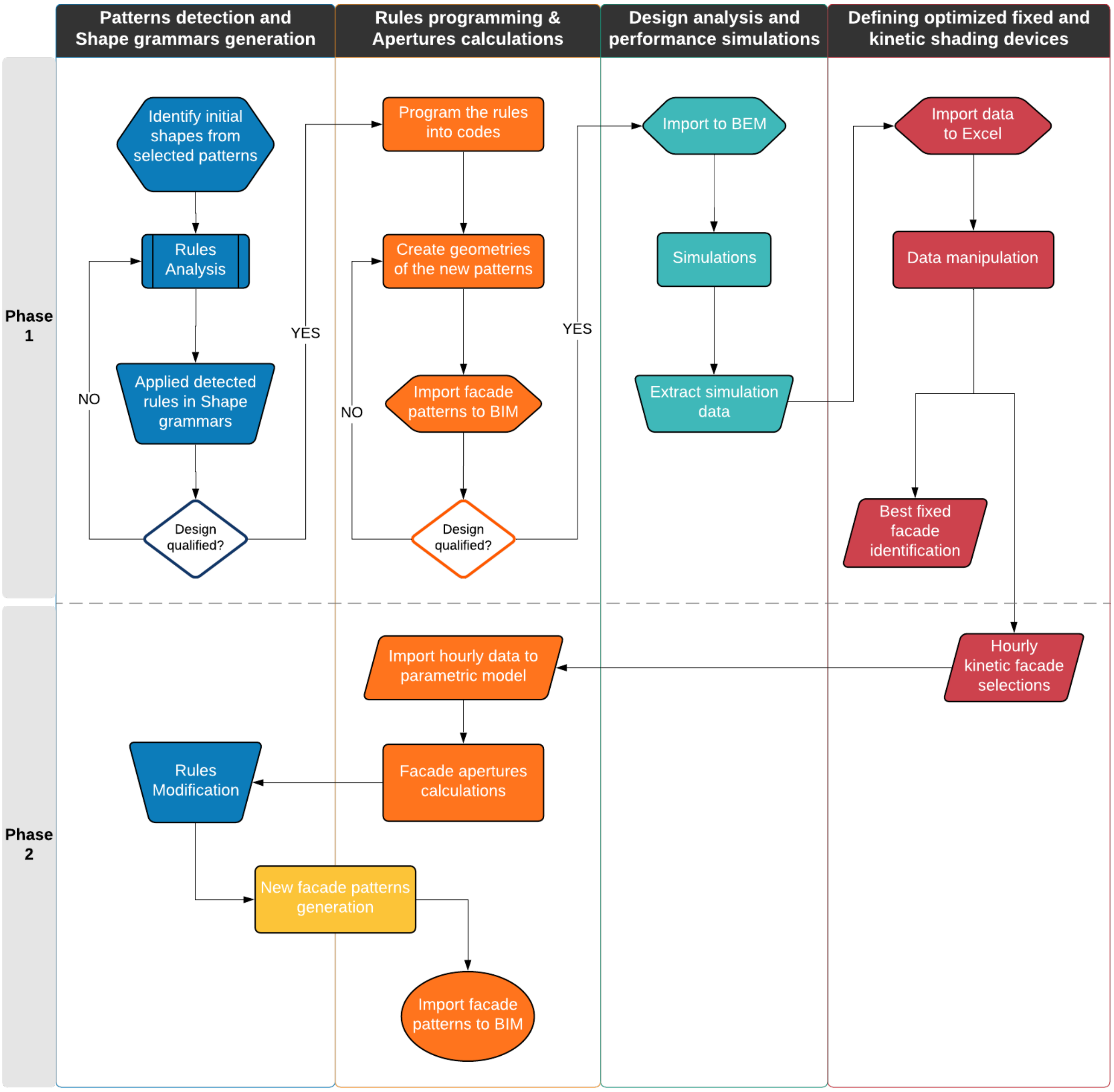

Figure 6.1 Macro-level KiSS System Framework. (Source: Author).

The framework incorporates analytical and generative shape grammars (ASG and GSG), sustainable design analysis (SDA) and building information modelling (BIM), coupled with visual programming (VP). The key concepts, creation of rules and language of shape grammar, patterns variation, and approach to new pattern generation using computational design are elaborated.

The proposed macro-level framework consists of four sub-schemes, each focusing on their distinctive design objectives, requiring from designer to both creatively explore and control decisions made at transitional points of each phase. They are grouped into four key stages, as shown in Fig 6.1:

(1) Patters analysis, shape rules creation and form generation,
(2) Shape grammar visual programming and aperture calculations,
(3) Daylight and energy consumption simulations, and
(4) Façade shading calculations and kinetic operation

Stage 1 and 2 are for schema development, representing creative exploration and visual programming; whereas stages 3 and 4 are for design validation and performance simulation.

The first two stages of the schema development are conceived as follows:

- **Conceptual development of design schema**

  The design schema is expressed as a combined outcome of creative exploration of Vietnamese patterns, motifs and ornaments using analytical shape grammars, followed by the creation of novel patterns using generative shape grammars, capturing the essence of shape emergence. Derived from the evolutionary framework of design thinking, the key concepts and principles of parametric design thinking are introduced, defined and illustrated. At this stage, the designer works at a conceptual level, using experiences, knowledge and imagination and establishing the process of transitioning from the paper-based design exploration to a computational model of design thinking.

- **Visual programming of design schema**

  The second stage involves encoding of a conceptual design schema by means of visual programming. A complicated set of visual programming nodes and their linkages form the means of new pattern computer generation. The generated patterns are then linked, through visual programming, to graphical information stored in a BIM model. This process sets up a basis for data exchange in the next stage of system development.

Stage 3 and 4 are as follows:

- **Sustainable Design Simulation**

  BIM data is configured, including construction and environmental data. It is then converted to gbXML file before being imported to building energy model (BEM). This stage requires knowledge of preparation for simulation since BEM's setup requirements are very different from those of BIM. Finally, thermodynamic simulations and daylight level calculations are undertaken, and final results are extracted for Stage 4.

- **Design Validation and BIM**

  The final stage is evaluating the sustainable design performance of models simulated in the previous stage. This stage involves a process of analysing data gained from the daylight and energy simulations for different façade apertures in a quest to define the best configurations. This evaluation process is explained in design science research methodology stated in Chapter 2. The evaluation of the system is validated through the comparison of a performance of the unshaded facade, a performance of "best-fixed" façade configuration and performance of a number of configurations of kinetic aperture openings which are adopted in the proposed design (e.g. 20%, 40%, 60%, 80%).

The four stages do not have to remain distinct. At each stage, the designer might find it necessary to 'look ahead' to the next stage and 'look back' to the previous one, especially for the two middle stages: the schema encoding stage and the design evolution stage.

6.2 Stage 1 and 2 - Shape Grammar Patterns Generation

Design is about change; design systems are often formalisms capable of accommodating a notion of change. The manner of change affects the way the worlds of possible designs can be explored. A particularly enticing and related concept to this research is that of *emergence* (Mitchell, 1993; Stiny, 1994, 1993)

The framework proposed in this research has two parts: the shape creation, composition and generation part and the BIM integrated façade pattern computerisation part (Figure 6.2).

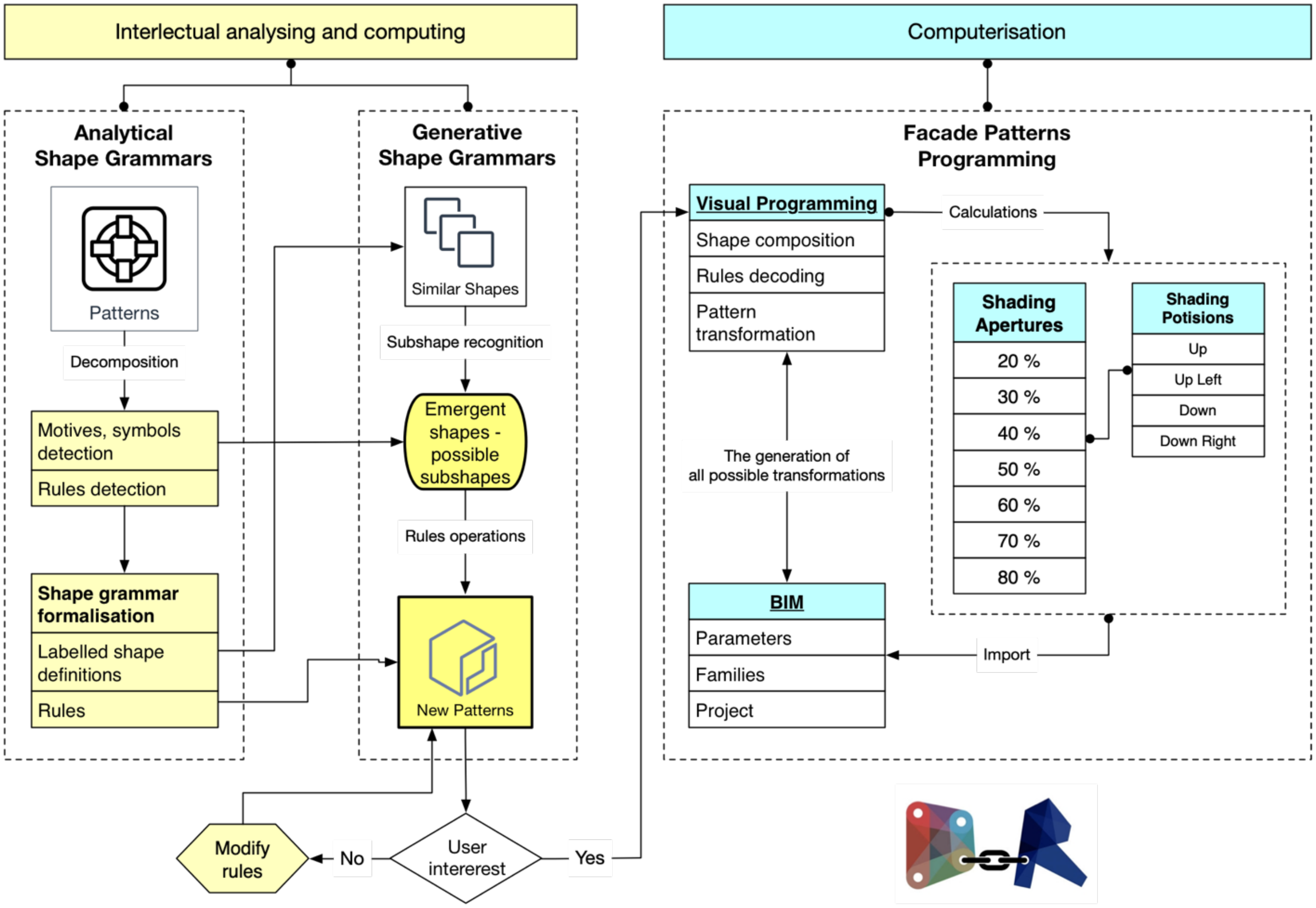

Figure 6.2 Framework for shape grammar patterns generation and BIM integration of dynamic shading systems (Source: Author).

Firstly, the history and origins of traditional Vietnamese patterns, motifs and ornaments were researched, and their morphological analysis was undertaken. This analysis revealed the existence of underlying coherent geometric language, the discovery and structure of which is discoursed in further detail in the sections to follow. Within this language, the shape vocabulary elements along with their spatial organisation rules and principles of the compositions are defined. The resulting formal language is then represented through a parametric shape grammar and integrated with BIM by means of visual programming.

6.2.1 Reflection - The Way of Seeing

Research in the 1970s and 1980s established a key concept for exploring and demonstrating SE. Central to the reasoning of SE (Steadman, 2008) is the creation of its continuous and recurrent evolution. One of the recognised interpretations was proposed by Schon (Schon, 1983), in which design thinking functions in a '*seeing–moving–seeing*' model. Indeed, Schon interpreted the conceptual design process as the designer having a "*reflective conversation with his or her ideas*" through design drawings, the process which becomes essential in further design exploration and shape generation. Schon's implicit sequential model could explain emergence via creative actions that inform alterations of the illustrations of drawing objects. '*Reflection in action*' model (Stiny, 1989) interprets this concept via creative reflection on sketch exploration, leading to actions.

The first model presents a formal and semantic understanding of design, where '*moving*' implies shape relations and rule conversions that are rooted in a computational archetype. Both methods acknowledge the iterative and often contradictive nature of design thinking as a fundamental part of research in visual representation in design. While the Schon's model proposes possible explanations of the psychological emergence in design thinking, the strength of Stiny's approach lies upon the delivery of a representing structure for the formalisation of visual reasoning in shape generation (Stiny, 2006).

A shape emergence process is important in this research, to enable for ambiguity to be creatively explored in the design. For example, if the researcher is concerned only with the exploration of triangles as underlying schema, then only the triangles will be seen (Figure 6.3a). However, a change in the "way of seeing" will find a trapezoid in Figure 6.3b, which was not apparent in Figure 6.3a. Hence a notion of *shape emergence* becomes evident.

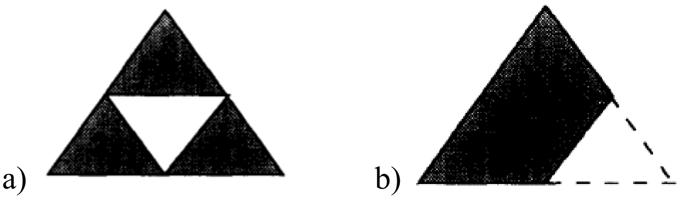

Figure 6.3 (a) Five equilateral triangles, only three shapes are exposed. (b) Implicit to explicit – an emergence of trapezoidal shape. Source: (Gero and Yan, 1994).

6.2.2 Shape Emergence Process

According to Gero et al. (2006), there are two processes that affect the notion of visual emergence in design: shape emergence - the process of exploring potential emergent shapes in the original design, and shape semantics emergence - the process of recognising visual patterns that guide the composition from a simple shape to groups of shapes. The first one plays a vital role in design exploration that uses shapes to characterise ideas. The semantics, on the other hand, help make decisions, organise structures, and generate a final order of new geometric patterns from the author's drawings.

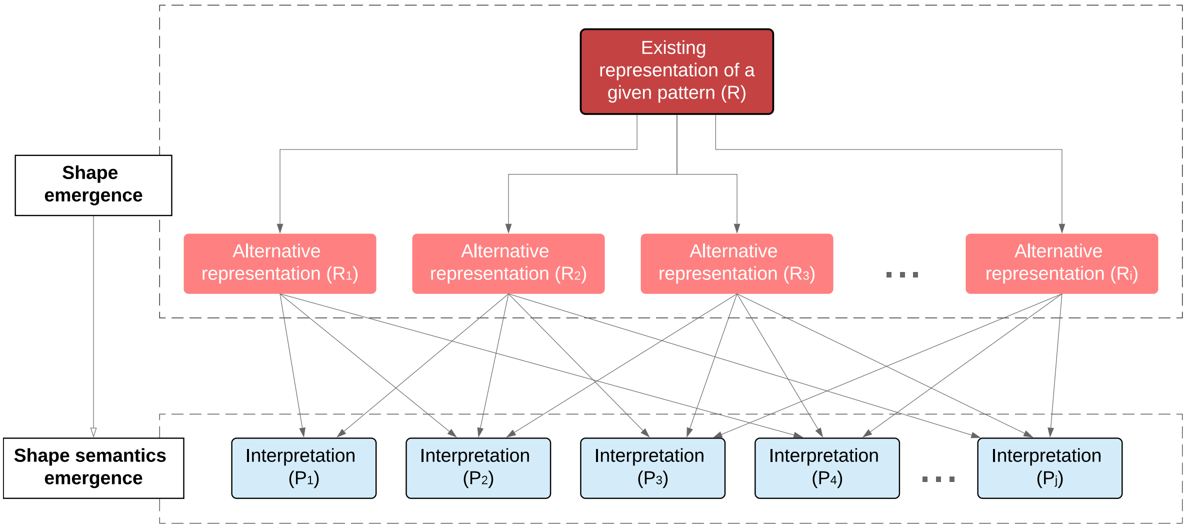

Figure 6.4 Framework for control of shape emergence in this exploration. (Source: Author).

In this research, emergence begins with a shape representation, providing a fragmentary view of the given traditional patterns. From this view, it is possible to gain some partial alternatives, resulted from Schon's '*seeing–moving–seeing*' concept. The general framework for this is shown in Figure 6.4, in which the representations R_i are the primary computational depictions, in the form of basic transforming rules and shapes. From each R_i, further interpretations arise, based on Stiny's '*reflection-in-action*' concept. Any change of R_i may lead to several emergent properties. These two processes are outlined as follow:

1. Decoding the appearance of a given pattern by deconstructing its geometrical composition and exploring, through a process of '*seeing–moving–seeing*', a secret language inside enclosed shapes.

2. Gradually, through a process of '*reflection-in-action*', new and different shapes emerge, undercover different schemas through an exploration of possible semantics and pattern compositions.

6.2.3 Creative Design Selection

This research adopts the approach of Gero (1996) in which creativity participate with the creation of unexpected outcomes through a convergence of two schemas. The first schema carries a set of routine expectations, whilst the second schema evaluates unexpected results, exploring phenomena of shape emergence and ambiguity (see Figure 6.5). Creativity is hence seen in exploring the connections and relationships where others have not.

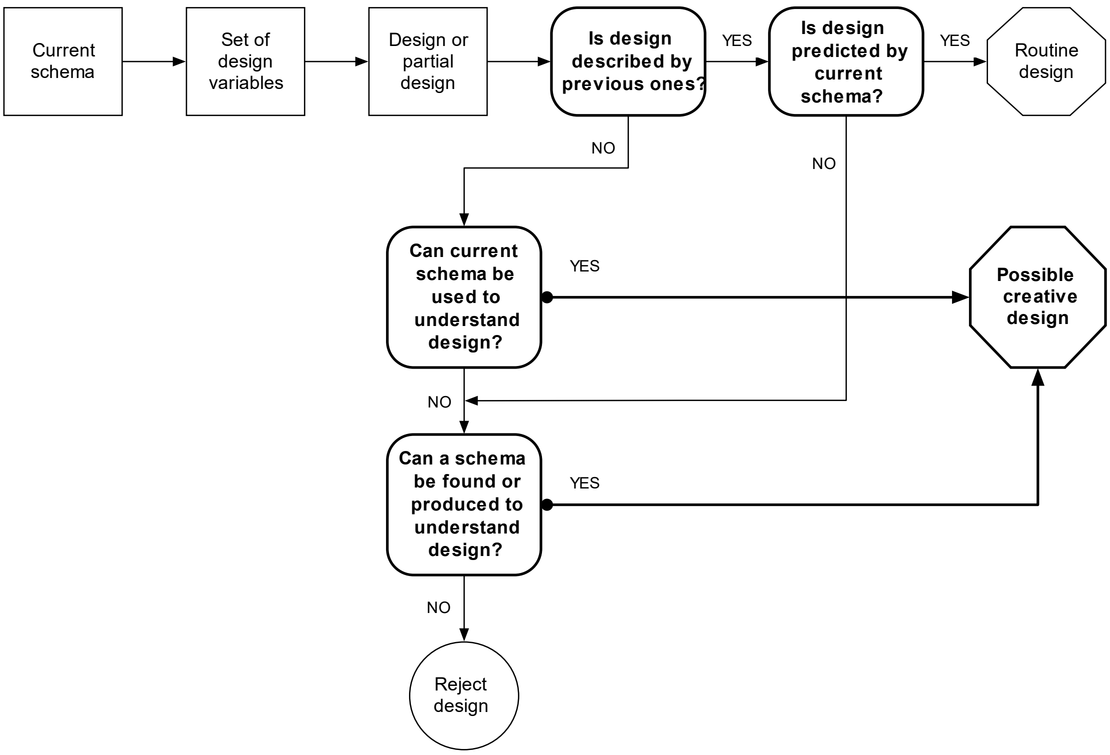

Figure 6.5 Creativity assessment process for new schema models in a shape emergence process. (Source: Author - adapted from Gero, 1996).

6.2.4 Analytical Shape Grammars – Recognising Emergence

The notion of creative exploration of new examples in a chosen style of traditional patterns is indeed exciting. It extends possibilities of the actual style by decomposing its original structure, taking imaginary links that share similar organisational qualities into consideration, enabling new ways to see those patterns and opening doors to novel designs. Such design evolution is founded under the detailed understanding of hidden structures and their formulation arrangements. In doing so, devised rules of shape grammar have to be flexible enough to allow unexpected elements of a pattern to emerge.

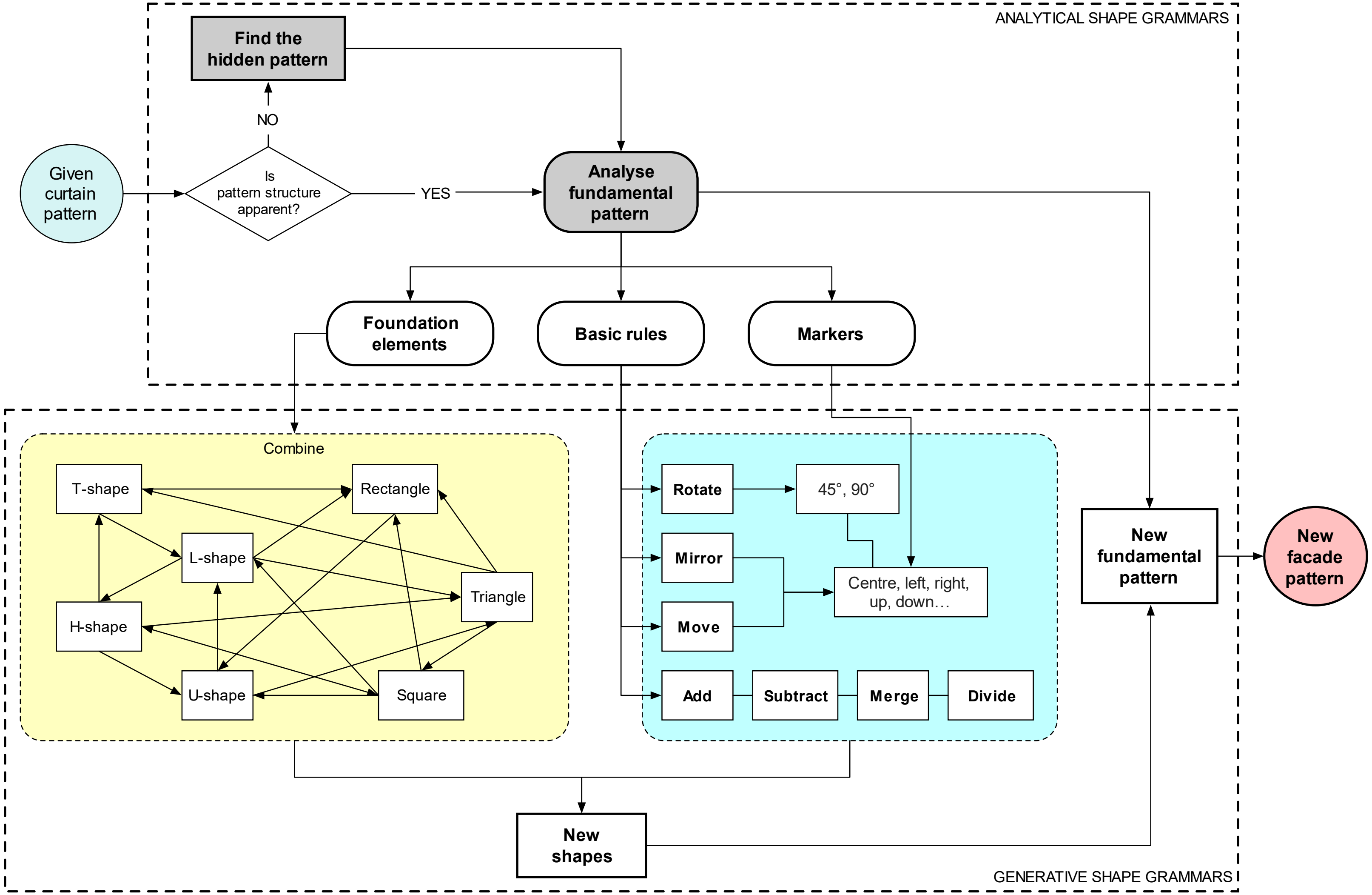

Figure 6.6 Framework for analytical and generative shape grammars (Source: Author).

The two classic types of shape grammars are analytical and generative. In literature, they are used a lot more frequently on the analytical side to understand the rules of the original design compositions. Much fewer studies aim to create evolutionary shapes based on analytical concepts. This research attempts to bring both into a framework for a novel pattern generation (Figure 6.6). The first phase – analytical shape grammars – deconstructs traditional patterns to extract design genes; hence, providing an understanding of how those patterns work. The second phase – generative shape grammars – discovers shape emergence through a creative exploration of novel patterns arising from these genes. Specifically, in the first phase, a pattern is analysed on the philological level by deconstructing it into fragments, and on the syntactic level by understanding the rules which embody their structure.

In the second phase, the approach adopted to an exploration of emergence phenomena can be represented by the process illustrated in Figure 6.7 below. Mainly, this process observes patterns as serial processes on their core structure. There can be other ways to know them, but a deep understanding of the multiplication can be found by sympathetic how the core structures are created.

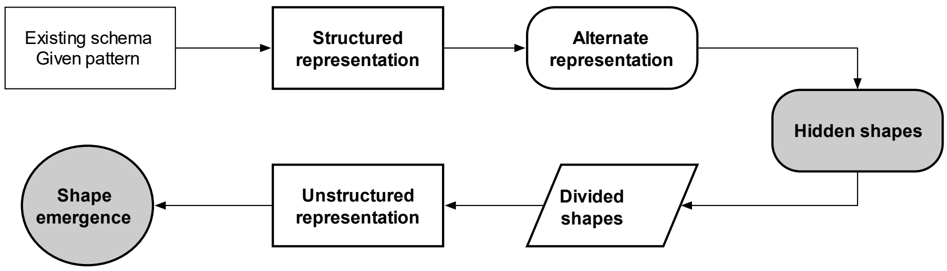

Figure 6.7 The process model for shape re-representation and emergence. (Source: Author - developed from Jun and Gero (1997).

To generate novel syntactic level models in this research, it is necessary to deconstruct original patterns, simplify their structure, remove the decorative components, and preserve a 'meaning' inherent to the pattern. For example, Figure 6.8 shows a rectangular frame element of a Vietnamese panel screen. At the first level of deconstruction, a high-level rectangular component consisted of 1 x 6 rectangles is established. The next level deconstructs it into three sub-structures: a composition of 1 x 3, 1 x 2 or 1 x 1 rectangles. The final level of deconstruction, in this case, can be undertaken by dividing a geometric region into subregions, hereafter termed as a *geometric decomposition.* Consequently, this process reveals T-shape, L-shape and a square as three shapes that represent key building blocks of this pattern, as no smaller shapes thereafter can be found.

Generally speaking, pattern language can be described as an overall arrangement of recursive combinations of different shapes (Figure 6.8 Example of pattern analysis of a panel screen with a clear pattern structure.), but it can also be thought of as the ’*underlying schema*’ that controls the overall composition. For instance, the panel screen in Figure 6.9, at first sight, shows no visible structure.

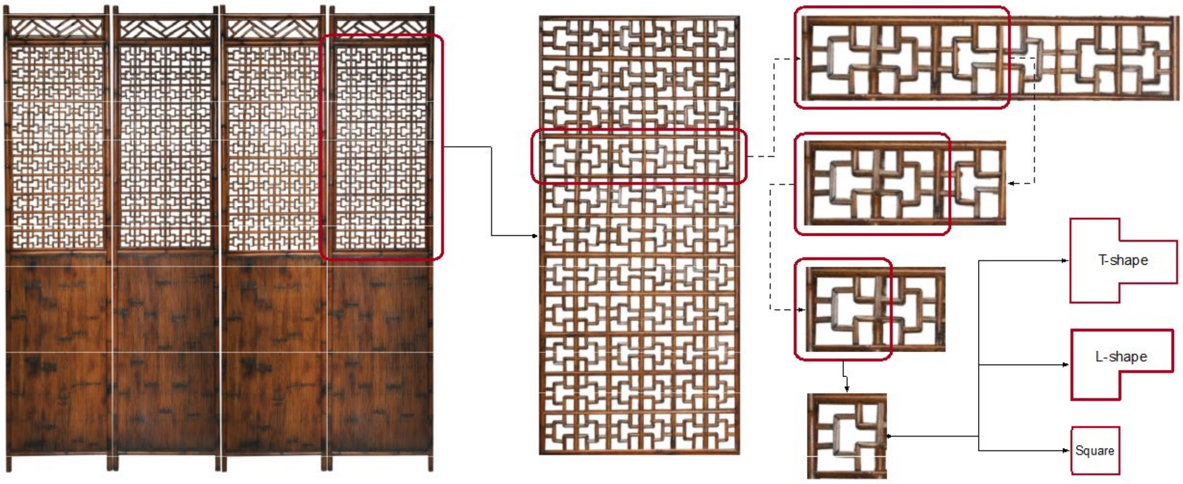

Figure 6.8 Example of pattern analysis of a panel screen with a clear pattern structure. (Source: Author).

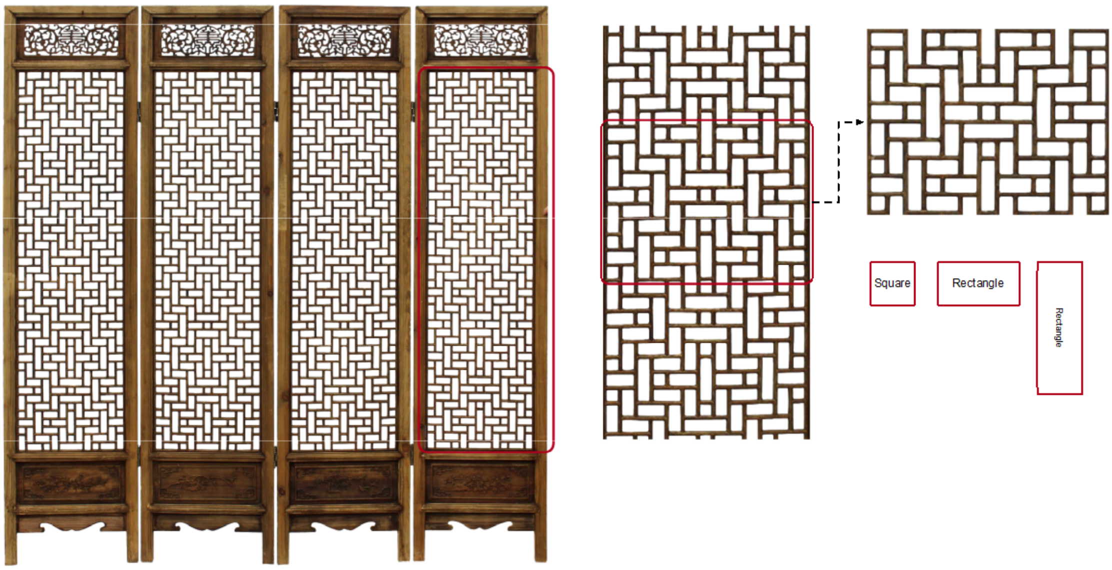

Figure 6.9 Example of pattern analysis of a panel screen without a clear pattern structure. (Source: Author).

The founding substructure of this pattern is exposed after discovering a ‘skeleton’ which guides the composition of the parts. There are no visual separations that help observe positions of a start and endpoint of a substructure. Thus, there are no boundaries. The researcher has to discover it via cognitive thinking. In some cases, multiple assumptions and failures will eventually lead to a hidden answer. The discovery of an overall 'skeleton' structure will often also bring out the fundamental building blocks (Figure 6.9, in red).

The third example (Figure 6.10) combines the two types presented above, with different shapes combined to form a number of building blocks, whilst the underlying 'schema' guides their overall composition (Figure 6.11).

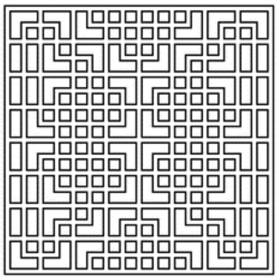

Figure 6.12 Regular traditional Vietnamese patterns with apparent base.

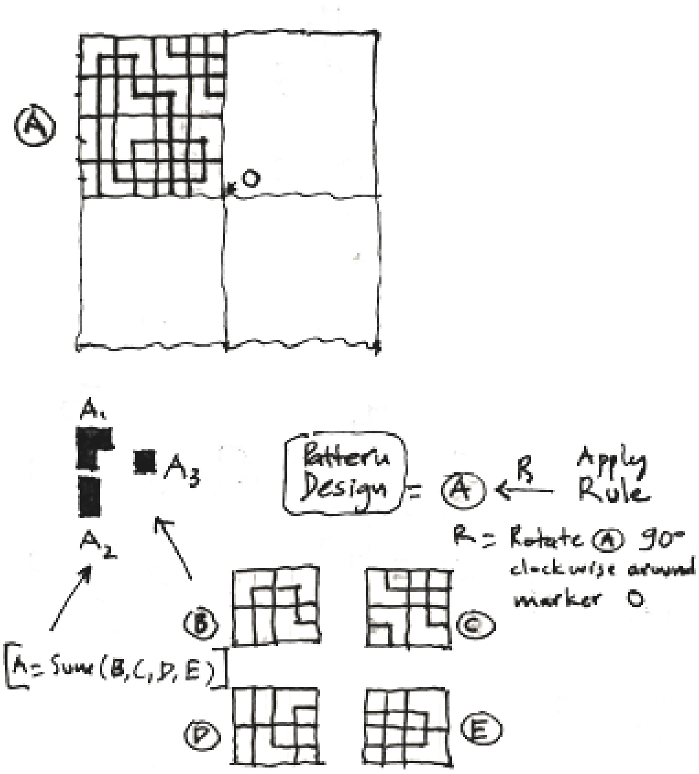

Figure 6.13 Analytical shape grammar used to recognise initial shapes from patterns shown in Figure 6.12. (Source: Author).

In particular, a rule A → B applies to a shape C (the given pattern) if the shape A can be found in shape C, or any part geometrically similar to it. More formally, there has to be a transformation rule T that combines shape A into a part of shape C. Once the transformation rule T has been discovered; it can be recursively applied to the shape C to create new shapes. Such a system, implicitly, includes all elements that can be formed, which at their least consist of the basic schema and geometrical transformations. Importantly, in developing a generative design system, a parametric illustration of rules and foundation schema must be articulated. These rules and shapes are understood from a set of instances, an example of which is shown in Figure 6.13. Disjunctive combinations of those instances form the fundamental elements that can be prescribed. What is not prescribed by the schema is the possibility for conjunctive combinations and therein lies the *expectation of unexpected*, or the *emergence* phenomena.

Designers mind understands shapes and their arrangements in a distinctively different way from the computational representations. In this research, the KiSS framework has harnessed the human intelligence and creativity and referred its combination of shape analysis and decomposition as a *human computation*.

6.2.5 Generative Shape Grammars – Anticipated Emergence for Novel Patterns

> *"The motivating idea of generative grammar is that we can gain insight into human language through the construction of explicit grammars. A language is taken to be a collection of structured symbolic expressions, and a generative grammar is simply an explicit theoretical account of one such collection."*
>
> Chomsky, 1956.

As stated in Chapter 5, the inspiration and classical notion of shape grammar primarily came from the linguist Noam Chomsky and cognitive scientists. A grammar is observed by what are the rules that describe a language and its structure, and about how the sentences are composed. Shapes, on the other hand, are much more than what this kind of description can express. For instance, a square shape can be seen as two rectangles or four squares. As human beings, we chose the way we see. Thus, shapes can be divided quite subjectively, in many different ways.

As explained in Chapter 5, shape grammar can be represented by a quadruple SG = (A; R; M; I). Here $A = \{A_1; A_2; A_3;\ldots; A_n\}$ that represents a finite set of shapes. $R = \{R_1; R_2; R_3;\ldots; R_n\}$ is a finite set of shape transformation rules, represented through Euclidean transformations (t), such as translation, rotation, scaling and other linear transformations. $M = \{M_1, M_2, \ldots, M_i)$, is a finite set of markers, $a \subset A \cup M$, $b \subset A \cup M$. $A \cap M \neq \emptyset$. $I = \{I_1, I_2, \ldots, I_j\}$ is a finite set of initial shapes, $I \subset A \cup M$. A recursive application of transformation rules leads to the creation of new shapes with increasing complexity of composition. Rule application results in a new shape $C' = C - (A) + t(B)$, where A is a transformed shape, C is the previous shape and B is a transformed replacement shape.

Figure 6.14 below shows concept sketches for a schema generation of shape grammar conceived in this research, consisted of a limited set of initial shapes and rules of transformation. The shapes in this scenario are chosen from different elements that form the lattices, such as, frame, sub-frame and blocks. Indeed, an initial square and L-shape and 2-d transforming rules, such as rotate, mirror, move, and add are used. It is evident from Figure 6.14 how simple rules can rapidly produce complex composites as a novel and different pattern schema emerges, with potentially legible roles in architectural design as building components. A dual-structure pattern is observed, consisted of a global composition structure and a local structure of motifs, in which the main evolution process emerges. It is interesting to note, that even with restricted expression of the grammar after only a few steps of recursive transformations, new sub shapes begin to emerge (e.g. T-shape in Figure 6.14).

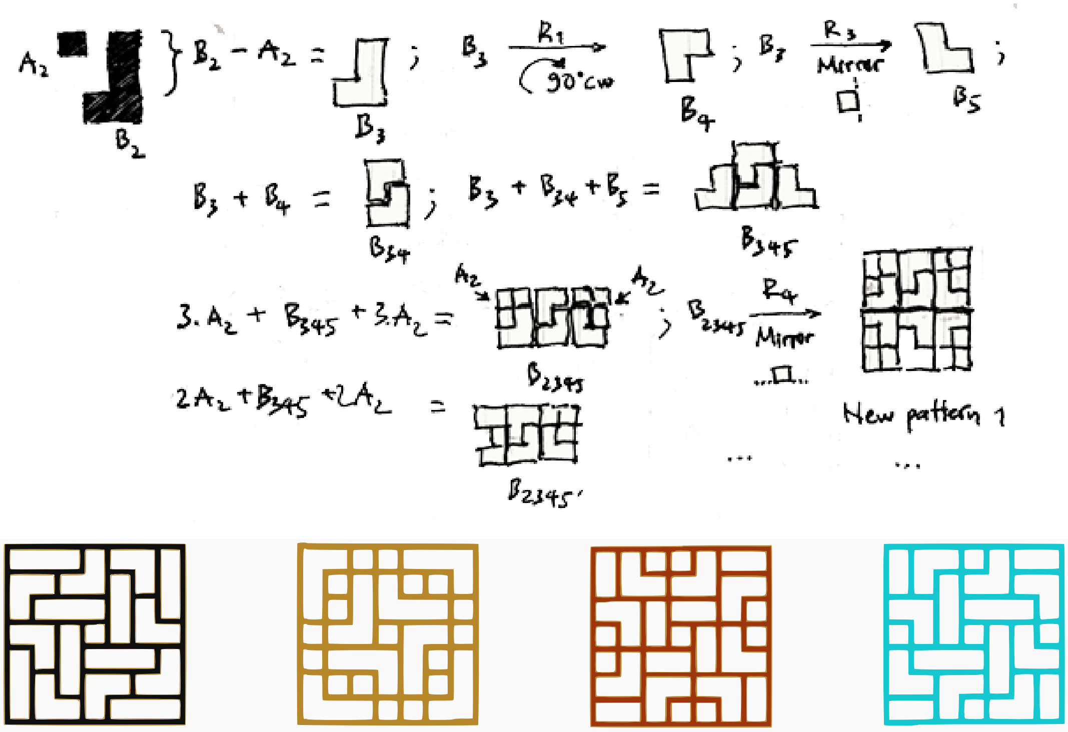

Figure 6.14 A new patterns schema emerging from the same set of initial shapes and rules (Source: Author)

These newly formed shapes are not irrelevant, in contrast, they should be seen as a new generation of the family, and their essential genes must be maintained. This will inevitably lead to an even higher number of combinations that could create final compositions with an appearance that visually conflicts with the original design intent. Thus, the designer must be in control of the shape emergence and intervene, if necessary. Such a process can be defined as '*anticipated emergence*' (Knight, 2003; Knight and Stiny, 2001).

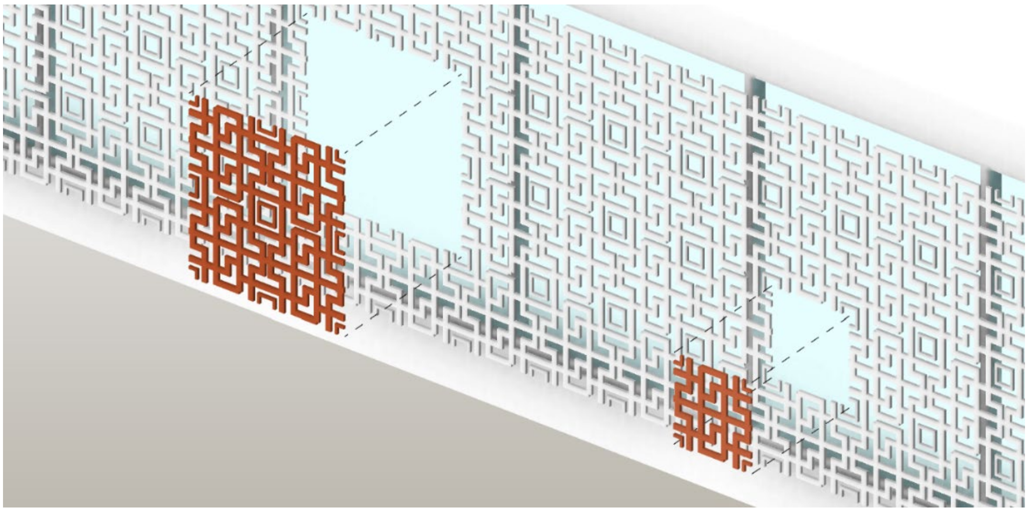

Figure 6.15 Façade shading system based on the shape grammar patterns encoded in BIM, resulting from the design in Figure 6.14. (Source: Author).

Figure 6.15 illustrates an example of the design of the façade shading system based on the shape grammar explained above, visually programmed and integrated within the BIM environment. As discussed already, the same shape grammar setup can lead to an emergence of new pattern schema, often just by a slight alteration of transformation rules.

The final phase is design realisation. In this phase, the designer explores the potential of a conceptual schema to provide an architecturally legible resolution of a façade shading system, as visualised in Figure 6.16 below.

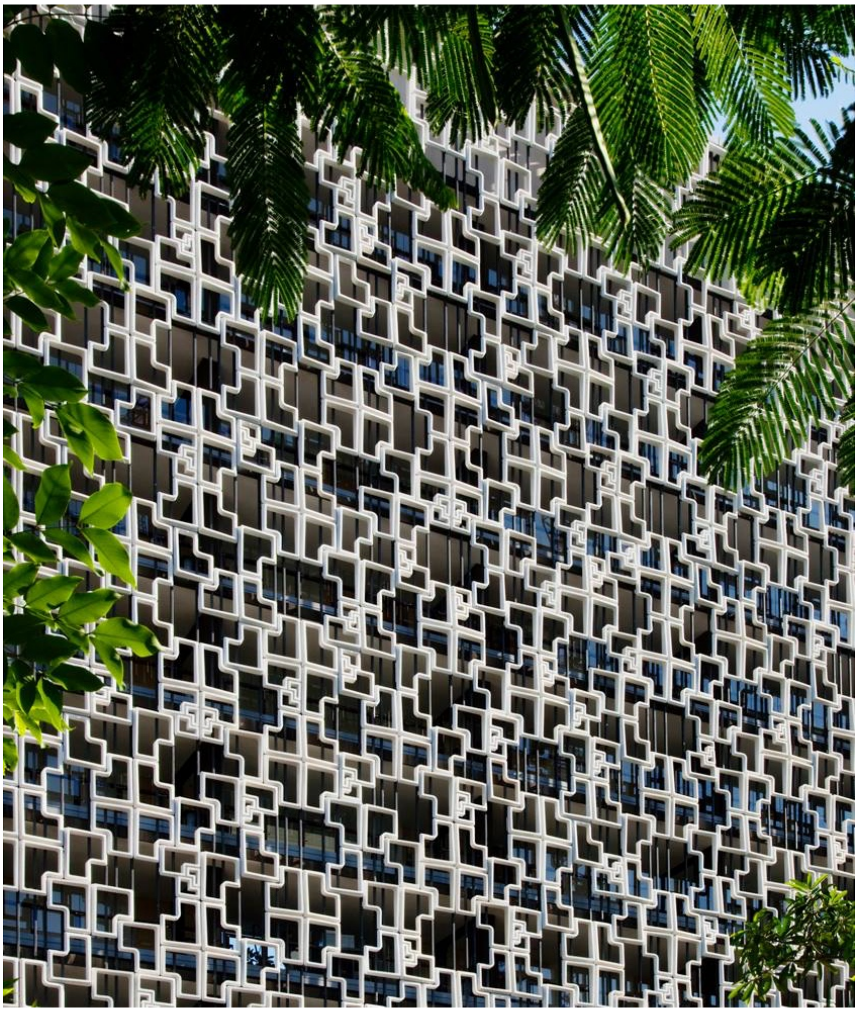

Figure 6.16 Design visualisation of conceptual façade shading system based on the shape grammar presented above. (Source: Author).

6.3 Stage 3 - Façade Shading Design Generation – Defining the Kinetic Concept

The term 'Kinetic' originates from antique Greek κινητικός (kinētikós), "one who puts in motion" (Wiberg, 2010). A Kinetic façade, deemed in this research as of architectural surfaces, can be defined as a transformable device that animatedly occupies pre-determined physical space, or a moving organism able to distribute a joint space to construct new spatial compositions (Fox and Kemp, 2009). Over the past two decades, research and practice in architecture have seen the advancement of dynamic solar shading and natural light control systems, in which vertical or horizontal rotatable components, made of metal, glass, and textile modules (Elzeyadi, 2017). The most related model of kinetic façade to this research is a Jean Nouvel design in 1987, the Institut du Monde Arabe in Paris (Radford et al., 2014). The design is special in the sense that national, cultural identity was taken into account, small-scale patterns from Arabic ornamental art are observed, analysed, and then amplified up to the extent of a mid-rise building facade (Mitrache, 2012). The façade comprises 240 holes (or lens apertures) in the form of aluminium diaphragm blades, triggered by square photoelectric units that open and close at certain times, based on a set of rules, acting as a lighting control device (Lo Turco and Pagliero, 2018).

Another concept close to this study is an Aedas's design in 2012, the Al Barh Towers in the UAE. This design is motivated by one of the Islamic traditional motifs, the "Mashrabiya" (Giedrowicz, 2015). Two 150-meter-high towers are enclosed by hexagon-shaped grid structures equipped with dynamic solar shading systems, which comprise triangular units so-called folding origami umbrellas. The Mashrabiya units are assembled into zones and are controlled by Siemens' sun-chasing technology that regulates the umbrellas' opening and closing angles, with 3 predefined positions – folded, intermediate, unfolded. The "Mashrabiya" is wooden lattice screens uncovered in vernacular Islamic architecture and used to improve privacy and environmental adaptation, involving natural ventilation and lighting control (Attia, 2016). Functionally, they are very similar to Vietnamese traditional bamboo screens; the difference is Mashrabiya panels are often fixed on walls and doors, while Vietnamese ones are flexible and can be manually moved or rotated for layout changing purpose.

Two ideas from Jean Nouvel and Aedas have paved ways for much academic research concerning sustainable shading devices, promoting computer-controlled, algorithmic, and rule-based designs, especially in theoretical studies. However, in terms of shapes, the concepts remain ancient appearance of the motifs; no geometric innovations have been explored.

In this context, to automate and implement rule-based operations in an exploratory way, the rules and shapes that have emerged from the previous two stages need to be formalised in an algorithmic, parametric format, so that they can be used in a practical architectural design workflow – a BIM model. However, a conventional way of modelling objects in BIM tool (Revit, in this research) cannot effectively deploy a shape grammar generation process. Indeed, although the BIM objects are conceived to be controlled by the parameters and constraints, they are created by a direct and straightforward input-output method; hence, no mechanism to implement the shape grammar generation process can be created in BIM.

Computer implementation of shape grammars, however, can be done in a visual programming (VP) environment. There are several studies that attempted to do that, but the use of those frameworks for shape generation has been limited since they do not explicitly and directly link with a BIM model. This research takes advantage of a recently developed visual programming tool that is fully integrated within the Autodesk BIM environment (Revit) –

named Dynamo. It allows the rules for both shape generation and transformation to be encoded, in the form of nodes and linkages, based on morphological and topological relations among geometric components. Furthermore, its platform-specific API allows for direct coding within a Python scripting environment, if needed.

Most importantly, visual programming enables the simulation of the operation of kinetic shading system, which is at the core of this study. It does so by programmatically controlling both the opening ratios – or the apertures – and positions of the shading device. The section below gives further explanation.

6.3.1 Façade Apertures Generations – Unanticipated Emergence

Ultimately, the purpose of this design process is to control the kinetic movements of the shading devices which response to natural light availability and energy consumption of the space it shades and, simultaneously, proves its cultural value via the architectural appearance of the patterns on it. The kinetic movements and pattern compositions together form the term 'façade apertures' used in this research.

Taking inspiration from a concept of '*unanticipated emergence*' (Stiny, 2001), a unique approach to aperture control has been created by means of proposing a dual-layer shading device system. Coming with designer's flow of thoughts, this nature of emergence strongly supports shape's evolution; it helps communicate between knowledge-based (anticipated) and generative systems, especially in the conceptual stage, which is intangible, when the free exploration of innovative, unforeseen designs is central, since '*Unanticipated emergence makes much of design happen'* (Knight, 2003). Also, it helps bypass the sub-shape and marking problems when coding shape grammars, because they are very hard to be computerised (Gips, 1999; Tapia, 1999). To date, these problems remain unsolved. In fact, James Gips, who was a supervisor of Stiny, pointed out that *'People who use shape grammars or want to learn to use them tend to be visual in their thinking. People who implement software must be good symbolic thinkers; ... People who think well both visually and symbolically seem to be quite rare'*. Moreover, human computation always goes with ambiguity and imagination, which, to some extent, makes it superior to machinery computation (Jun and Gero, 1998; Knight and Stiny, 2015). The proposed calculation below takes advantages of both, allowing rule operation under control of creators.

Functionally speaking, two layers are necessary to control a wider range of aperture openings, as single-layer design only shades up to 40% of the glazing behind it, which is not enough given that the overall system is required to shade up to 80%. Of course, shading of glazing could be controlled by other systems and their kinetic movements, such as rotatable horizontal fins or vertical rotatable louvres, or shading systems with a dilating, camera lens like kinetic movements. However, those systems are limiting in terms of implementing our design intent, and therefore a concept of a dual-layer shading system was adopted. The pattern schema for the first (inner) layer is grammar-based innovated Vietnamese patterns, as seen in many traditional Vietnamese doors and windows, only on a larger scale (Figure 6.17 and Figure 6.19).

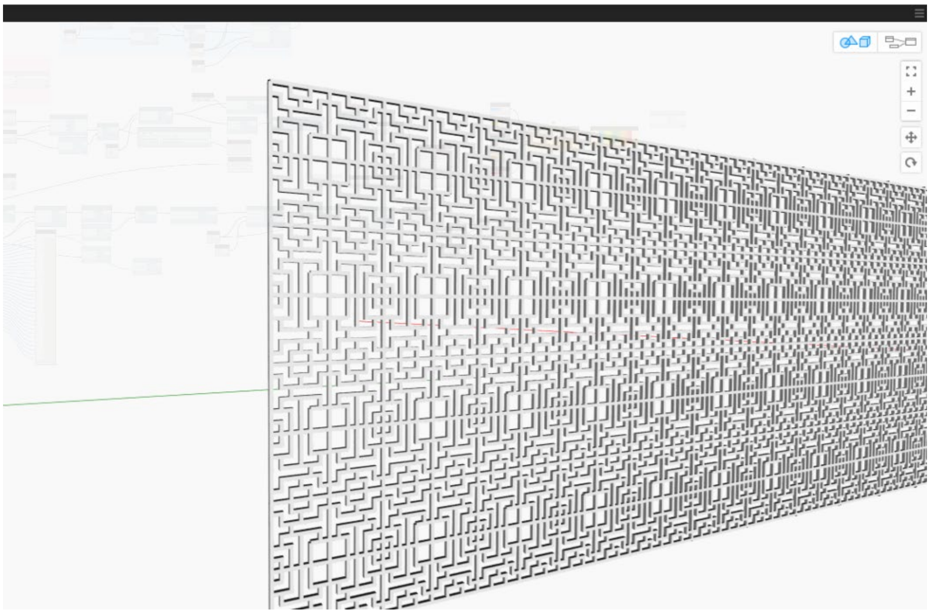

Figure 6.17 A GUI representation of visually programmed schema (Dynamo) for the inner layer. (Source: Author).

Alternative versions of the pattern schema were explored too. The dual-layer system needs to create and control eight percentage aperture openings, ranging from 0% to 80%, with an increment of 10%. In conventional search in this field, rotation angles are utilised, the equivalent numbers are in degree (0^{o} – 90^{o}), with an increment of 10^{o} or 15^{o}. Figure 6.18 explains the computational framework for the parametric control of these percentage aperture opening.

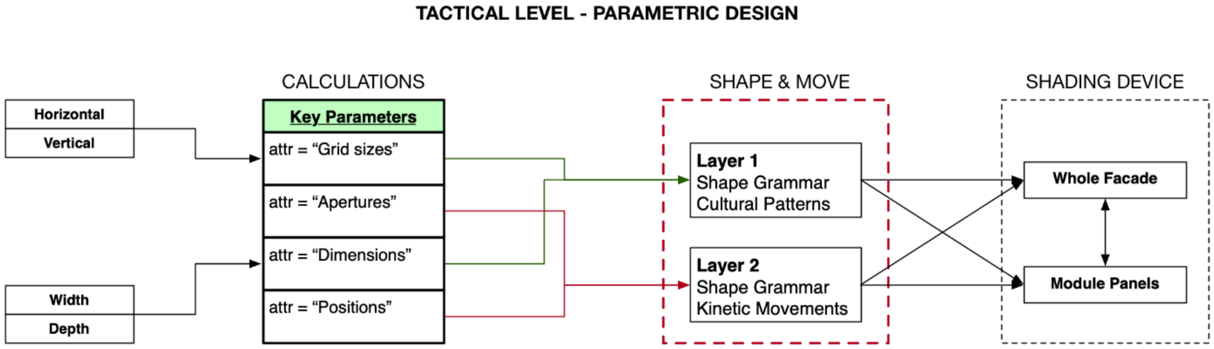

Figure 6.18 Framework for façade parametric control of percentage aperture opening. (Source: Author).

The framework is responsible for generating different façade sub-panel configurations in an automated fashion, whilst satisfying the following criteria; controlling its position in a geometric domain, adjusting its shading through control of percentage aperture openings, and providing an interconnected structure, thus ensuring constructability.

Importantly, it is a second layer that makes the proposed system distinct from others. It reflects the designer 'way of seeing' and the way the contemporary interpretation of traditional patterns is achieved through exploration of the concept of 'unanticipated emergence' in the shape grammar composition. A useful example of this kind of shape grammar is given in Figure 6.19. In this simple demonstration, the emergent shapes are generated based on the re-interpretation of the original transformation rule R_1. Hence new rule R_2 emerges, creating a new shape B (right) which is structurally distinct from shape A (left) of R_1, leading to unexpected emergence. Of course, it is important to recall that what is anticipated, or unanticipated emergence will always be relative to the knowledge and the visual perception of individual designers (Stiny, 2001). Also, emergent rules like R_2 can formalise further syntactic calculations, and offer different, more expressive, and more 'designerly' (in the words of Stiny) grammatical varieties.

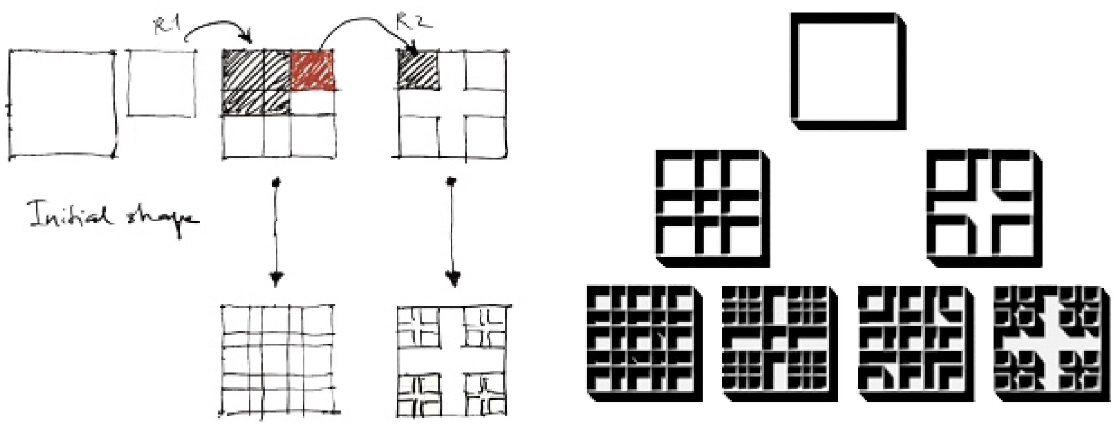

Figure 6.19 New, unexpected patterns generated from emergent rules. (Source: Author).

Detailed examination of such conceptual shape grammar models reveals a process of learning, as the construction of new (observational and descriptive) pattern knowledge and its reconstruction, re-organisation, in which shape emergence creatively thrives, and with it the 'expectation of unexpected'. This gives an interesting interpretation of the way we understand and support creative design within the computational environment. The opposite is also true, as faithfully analysing, deconstructing and replicating pattern schema, tends to lead to anticipated emergence, or 'expectation of expected', as shown in Figure 6.19.

Remarkably, this is the point where shape grammars meet another important mathematical theory used in the field of architectural geometry – the *fractal geometry*. It is closely associated with this study since fractal geometry has been widely used in ornamental art, pattern design as well as in interior decorative design and exterior façade design, for instance, cathedral of Anagni in Italy, Humayun's tomb, Shiva Shrine, and Hindu temples in India, Frank Lloyd Wright's Palmer House, and Le Corbusier's modular, proportional systems of φ and the Fibonacci sequence (Lu et al., 2012).

The term '*fractal*' originates from both Latin and mathematical variant, *fractus* or *frangere*, denoting *to break* or *fragment* (Mandelbrot, 1975). Historically, Mandelbrot (1975) systematised concepts of Karl Weierstrass (1872), Helge von Koch (1904), Sielpinski (1915), and other mathematicians to officially introduced fractal. He then classified fractal in two categories, *fractal geometry* and *fractal dimensions* (Ostwald and Vaughan, 2016a). Fractal geometry refers to a kind of deep geometric occurrence that involves continuously applied feedback processes, in which the output of an iteration is used as input for reiteration (see Figure 6.20).

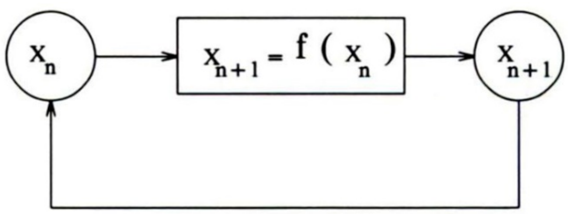

Figure 6.20 Graph of a fractal feedback process (Ruiter, 1988).

The most primitive fractal is the Koch curves by Swedish mathematician Helge von Koch, in which, regardless of how big the enlargement is, the shape appears the same, for example, see Koch Snowflake in Figure 6.21: in each iteration, one segment of the object from the prior step turns into four segments in the next step. As the Koch Snowflake starts with three segments and a single line as a generator, the formula of its fractal is:

$$n = 3 \times 4^{i}$$

where n is the number of segments, i is the step of iterations. Hence, if $i = [1, 2, 3, 4]$ then $n = [12, 48, 192, 768]$. Hence we get 768 lines after only 4 iterations! Also, the length of a segment at i^{th} iteration l_{i} is one-third of it in the earlier step, which follows the equation:

$$l_{\text{i+1}} = l_{\text{i}} \times 3^{\text{-i}}$$

Thus, at iterations from 1 to 4, $l = l/3$, $l/9$, $l/27$, and $l/81$, respectively.

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Figure 6.21 Fractal set of Koch Snowflake - the first four iterations (Ostwald and Vaughan, 2016b).

In order to explore this the formula was applied to a square with T-shape as generator. Starting at a point that divides a side to the lengths of $2l/3$ and $l/3$ and using iterations from 1 to 5, it produces the resultant geometries shown in Figure 6.22 below. Here $n = 4 \times 3^{\text{i}}$ and $l_{\text{i+1}} = l_{\text{i}} \times (3/4)^{\text{-i}}$.

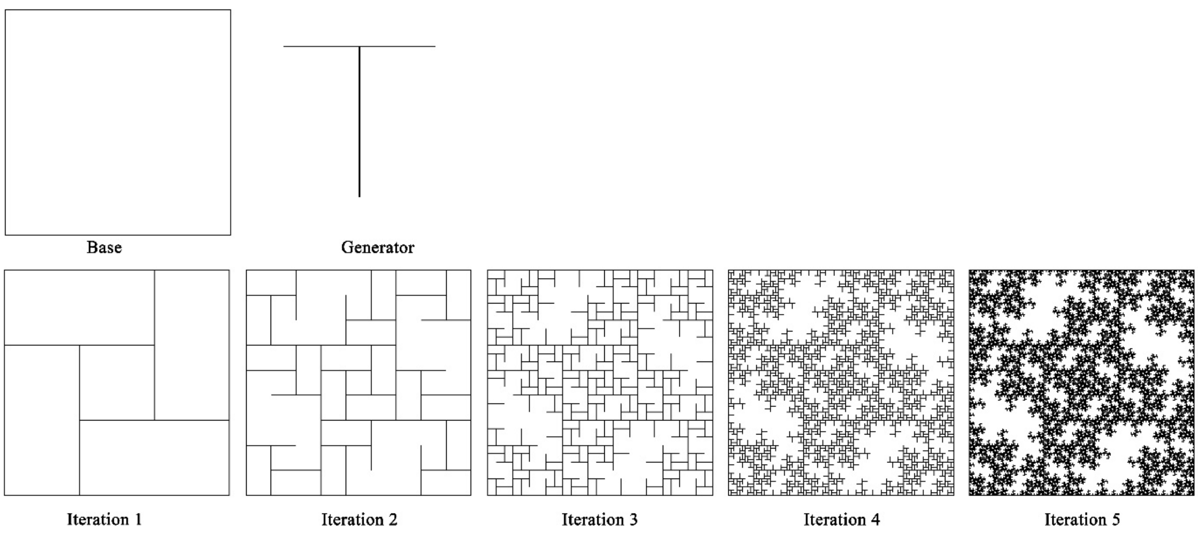


Figure 6.22 Fractal-style shapes for a simple Vietnamese pattern. (Source: Author).

However, as opposed to ideal mathematical fractals, like the Koch Snowflake, which feature beautiful figures of infinite parallel scalability (Peitgen and Richter, 1986), most natural and synthetic components of buildings are not scaled in such manner (Stanley and Meakin, 1988). Indeed, architects calculate lengths and seek ratios between them based on the Cartesian coordinate system (length, width, and height). In essence, the fractal geometry in architecture whilst diverse in forms, hence driven by different mathematical processes, van generally be grouped in three types: ‘Box-counting’ method of architect Peter Eisenman, originally from Fibonacci’s The Book of Squares (Ostwald and Vaughan, 2009), Geometric-mathematical methods (Bovill, 1996), and Geometric-intuitive methods (Espanés, 2003).

Following Eisenman and Bovill, Figure 6.23 illustrates the spatial operation of square as base and square as generator (void or solid, depending on *the way of seeing*), which consists of two alterations: the first one scales the generator up, down, left and right (a ratio of scale is 0.45); the second one renders them to the corners. Each iteration provides a grid of points for the next one. This simple experiment reveals how the diversity of possibilities can be achieved from a combination of fractal geometry and shape grammars in Figure 6.19.

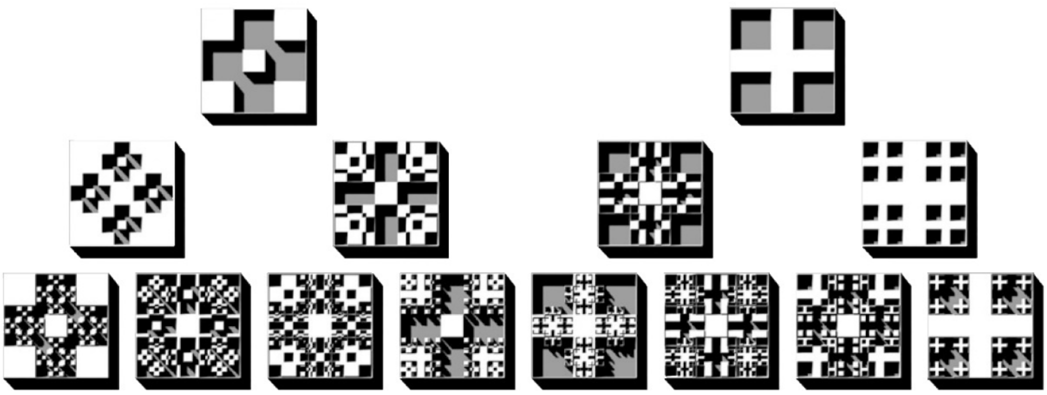


Figure 6.23 Some possible results of simplified fractal for Vietnamese patterns. (Source: Author).

Also, fractal can be generated using L-system, which was developed by Hungarian theoretical biologist and botanist Lindenmayer (1968a, 1968b), when he explained behaviours of plant cells and formalised plant branching patterns. Similar to shape grammars, L-system was built upon Chomsky’s Formal Grammars (Teboul, 2011; Teboul et al., 2013). The distinction is in the alteration process: in shape grammars, rules are applied once at a time, in a certain step; L-system’s rules are applied concurrently in all directions of the sequence. Whilst the IFS and L-systems integration could produce appealing forms, the automatic, mathematical computation cannot maintain the required cultural identity and metaphor of conventional patterns.

Conversely, by supporting ambiguity and vision, shape grammars offer better control in conserving the geometrical state with a philological standpoint between art and science, between form and function; hence, offer better means for *human computation* of pattern formation.

As mentioned earlier in Chapter 5 (5.2.2), the main limitation of shape grammars is the difficulty to match sub-shapes and choose which one to process. The 3 problems defined by James Gips (1999) still remain open questions. However, the lack of answers to these questions (especially parsing and inference), can be explained by the very complex tasks of sub-shape detection. This makes it practically useless in Computer Graphics, and that is why simplifications have been proposed to cope with the complexity of the shape grammar problem.

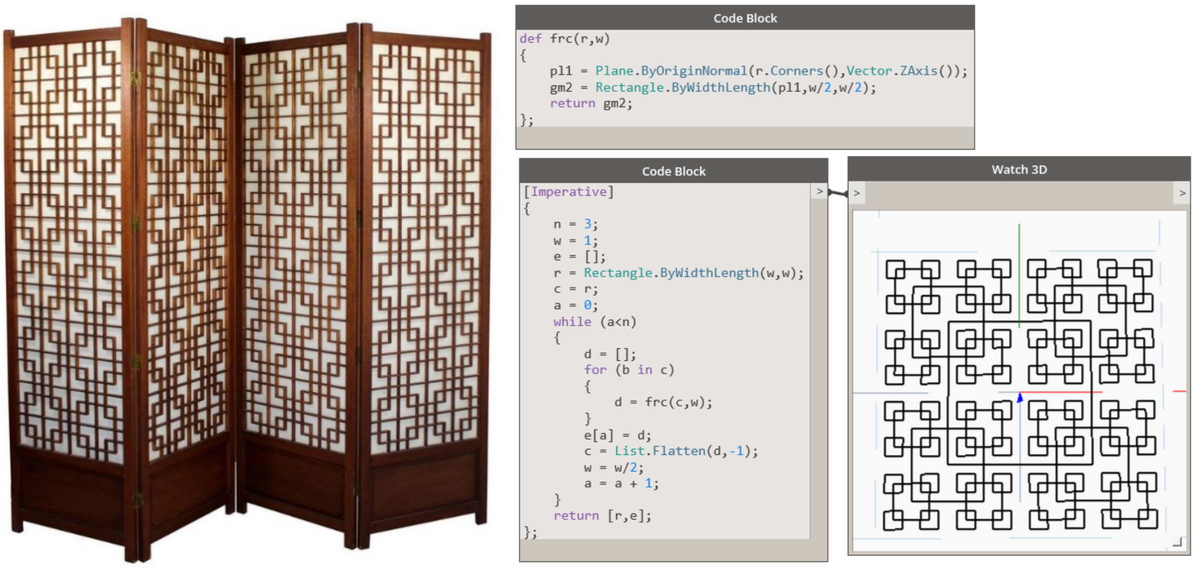


Figure 6.24 Traditional Vietnamese screen panel, with its shape grammar schema, decoded and translated to the digital environment by visual programming. (Source: Author).

A demonstration of encoding schema is illustrated in Figure 6.20 which explicitly determines original shape grammars are successfully translated to parametric shape grammars by means of visual programming. This is a pivotal step in the KiSS framework, making two worlds of *human computation* and *computational design* united. Indeed, initial shapes (squares) and transforming rules (move and add) of original shape grammars in Figure 6.19 are encoded in visual programming environment in the form of code blocks, by exploiting mathematics origin hidden within the screen panel's pattern. These shapes and rules are parameterised by attributes of quantity, dimension and direction (vector), and the grammars are then performed under purposely logic multiplication of elementary algebra. When the human computation settings are encoded, a whole new level of shape evolution is revealed.

Once the inner layer is created, visually programmed and represented within BIM (for example, see Figure 6.21), the next step is to code shape grammar schema for the second (outer) layer for shading. Together, both layers will control percentage aperture opening to establish an adaptive shading system. To retain their aesthetic appearance and cultural metaphor, the two layers operate kinetically without changing their core structural composition. The first (inner) layer also keeps its base grid static, i.e. it moves by lowering down or raising up its grid panels. The second layer, however, moves without being constrained to its base grid, moving its constituent atoms into places defined by the BIM-based generative system, free from the traditional pattern constraints.

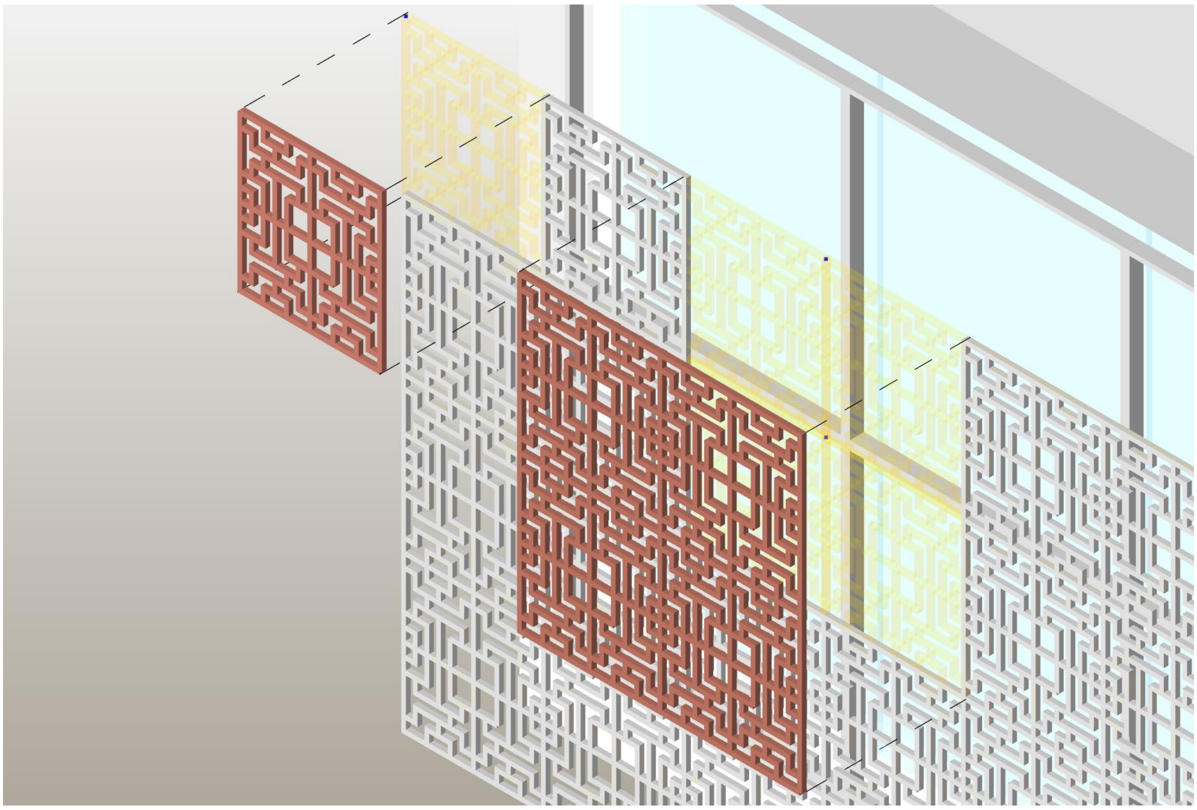


Figure 6.25 BIM model of the inner layer resulted from the pattern in Figure 6.14. (Source: Author).

The input for number and sizes of the atoms can vary so that the parameters and overall compositions of an outcome design in grammar can change. This raises the possibility of design to a whole new level. Designers can now control not only design aesthetics but also the number of outcomes; it can be a hundred, or one thousand, up to computer power they have.

For example, a 60% combined aperture can be established by an inner layer providing a 20% and an outer layer providing a 40% of shading. If the first layer panel provides a static 20% shading, then the second layer panel aperture requirements will be calculated to provide another 40%. The calculation of such area, based on 3x3 panel grid as shown in Figure 6.22, and three constituent atom shapes (or 'building block'), for example, T-shape, L-shape and C-shape would be based on the Eq. 6.1 below:

*PArea = (i * PArea_T-shape) + (j * PArea_L-shape) + k * (PArea_C-shape)* [6.1]

where i, j and k are numbers of the constituent shapes, *PArea* is percentage panel area.

Area of the shapes is pre-defined. For example, let's say that the area of a single T-shape in a panel is 2.5% of the overall panel area. Similarly, let's say that the area of L-shape and C-shape are 2% and 2.5%, respectively.

The Eq. 6.1 above now becomes:

*40% = (i * 2.5%) + (j * 2%) + (k * 2.5%)* [6.2]

Visual programming algorithm now comes into play, generating a number of possible results, such as [i, j, k] = [6, 5, 2] or [4, 6, 3]; and so on. Each result generates a new composition of the panel in the second layer. This complexity and flexibility can only be achieved in a generative computational system.

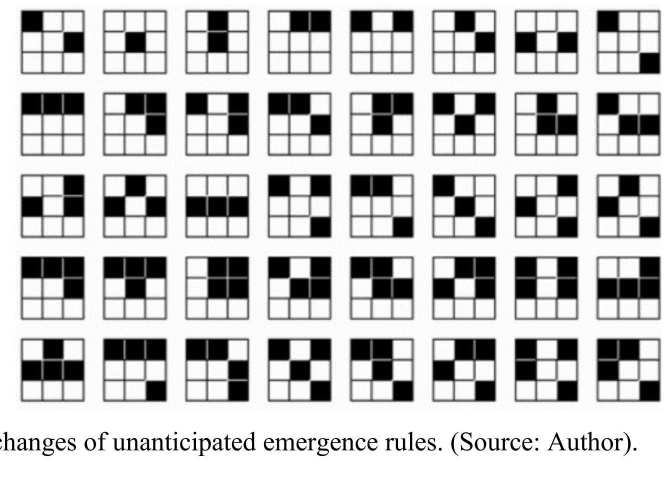


Figure 6.26 Parametric changes of unanticipated emergence rules. (Source: Author).

In particular, a type of 'voxel' arrangement is introduced in this decisive step to represent the 'building block'; the voxel relations result from the above-mentioned parametric calculation. This approach is similar to the works of Schnier and Gero (1995; 1996), in which they propose an approach to hand-code shape grammars of house floorplans, particularly from Frank Lloyd Wright's Prairie Houses, using Genetic Representations. Specifically, the Genes are coded as Entities (voxels) able to replicate the style of the houses. For this, the encrypting of the voxels is decided to be at lowest level conceivable, hence the term 'basic genes.'

Within context, Krstic (2010) uses 'Parts and Elements' for approximating shapes to create their hierarchical decompositions, which carry genuine shape properties. Such realism enables a design to be encoded out of the atoms of the analysed hierarchy. Principally, both the design and its elements are sums of atoms of the hierarchy.

In this research, by employing the algorithm in BIM-based generative system, the voxel arrangement empowers a logical search for the 'building block' compositions as well as their shading percentages. After this, it is now the decision of the system itself – the random selection, that picks a design for demonstration. This shape representation determines the generative power of KiSS framework, instituting a big library of innovative patterns.

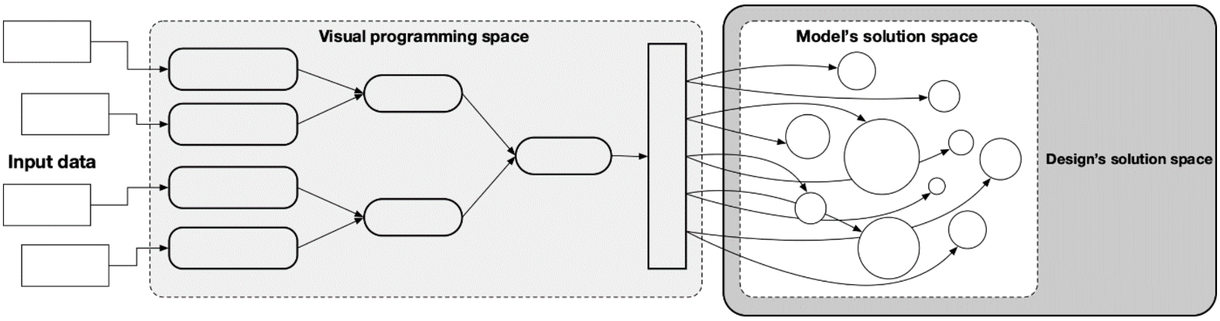


Figure 6.27 Diagrammatic representation of the structure of a parametric model. The parametric solution space overlaps with the design solution space. (Source: Author).

The process of parametric model creation is visually described in Figure 6.23 above, both diagrammatically and programmatically. Programming space interacts with BIM model space via execution of the code, providing instantaneous visual feedback.

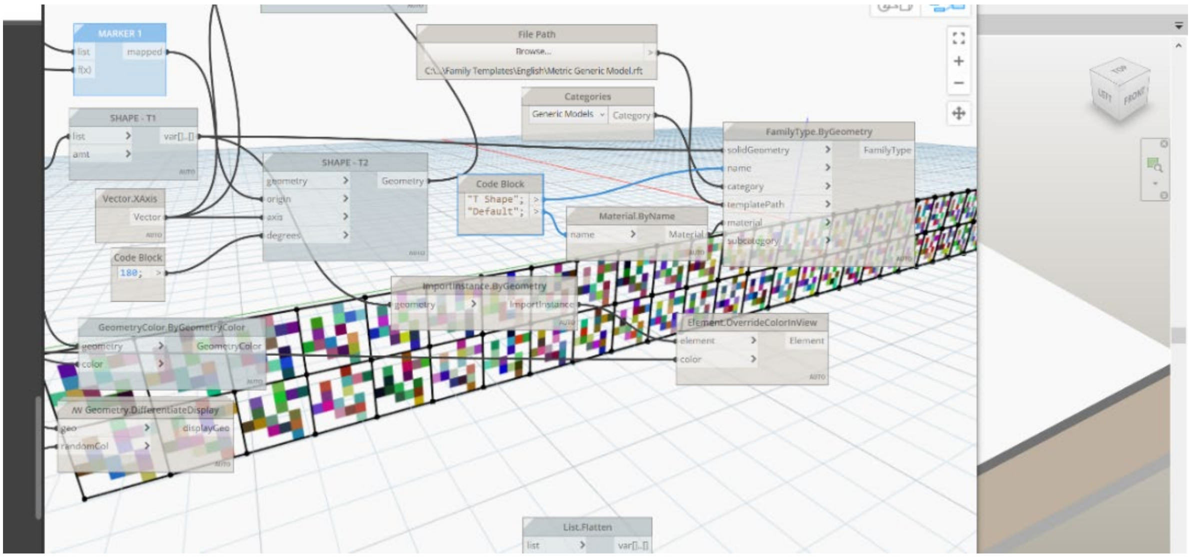


Figure 6.28 The ‘making’ of an outer layer from T-shape in the visual programming environment. (Source: Author)

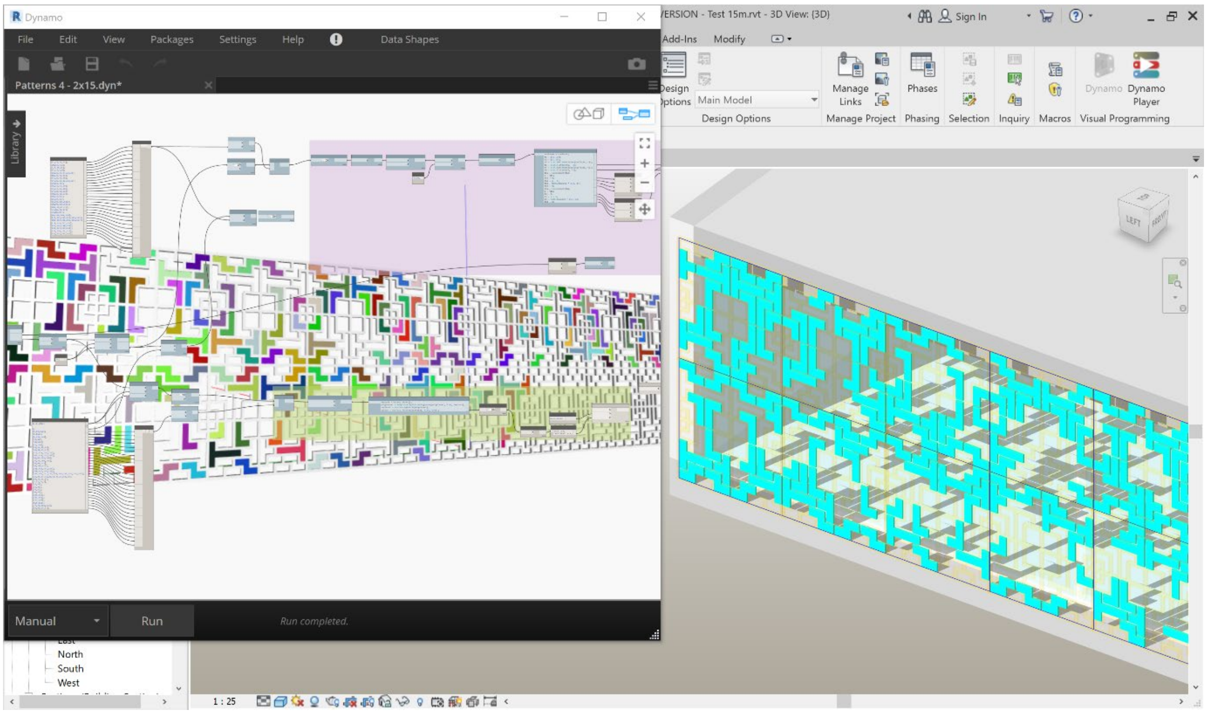


Figure 6.29 Random control of number and positions of both T-shape and L-shapes in the BIM-based generative system. (Source: Author).

Figure 6.24 and Figure 6.25 evidently show presentation of the parametric calculation in which, T-shape and L-shape are the building blocks, with the latter results from a combination of both.

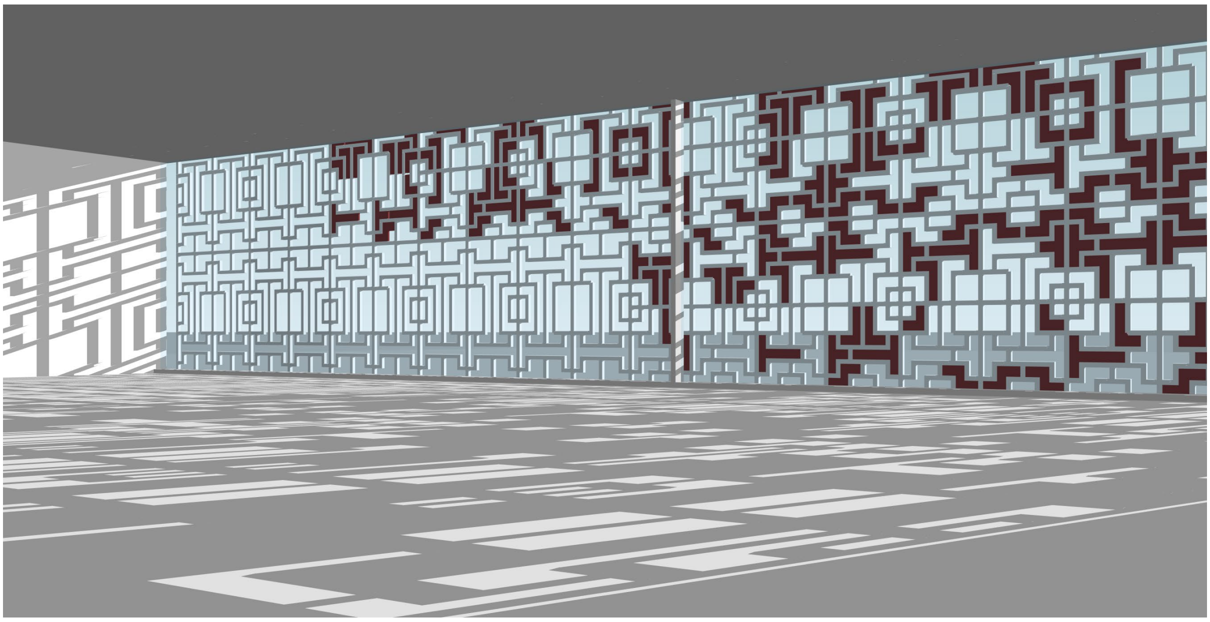


Figure 6.30 View from the interior, seeing the facade system in Figure 6.25 shading at the top-left corner. (Source: Author).

The programmed apertures, coupled with control of its dynamic positioning (see Figure 6.26) enables grammar users and designers to generate, analyse, and select a significant number of design alternatives, rapidly and efficiently, in a manner that is practically inconceivable in traditional design approach. However, a random generation of a vast number of configurations is rather pointless unless the criteria for adaptive operation are set and designs alternatives are tested against user-defined criteria. This process is explained in detail in the next section.

6.3.2 Determining the Adaptive Operation

As claimed by the current state of research in terms of 'adaptive façade', most studies lie between the scope of architecture, engineering, and advanced material. The term 'adaptive' is widely interchangeable with other words in literature, such as active, passive, adaptable, dynamic (Aguacil et al., 2019; Capeluto and Ochoa, 2014; Kasinalis et al., 2014; Ogwezi et al., 2011; Perino and Serra, 2015), bioclimatic, biomimetic (Loonen, 2015; Paar and Petutschnigg, 2017); intelligent (Ahmed et al., 2015; Al-Qaraghuli and Alawsey, 2016; Böke et al., 2019); kinetic (Formentini and Lenci, 2018; Hosseini et al., 2019; Mahmoud and Elghazi, 2016); responsive (Datta et al., 2014; Favoino et al., 2016; Sanchez, 2010); and many others. While this state of research does support a high level of complexity and creativity, it focuses mainly on technological sides of design and devotes little attention to cultural aspects of the facades. In other words, the missing link is the designs of 'making sense'.

This study promotes both; its key purpose is to design kinetic façade shading system based on a novel generative shape grammar, inspired by traditional Vietnamese patterns and motifs, and able to self-adjust to control its kinetic movements to respond to natural light provision, whilst minimising the energy consumption of the space it shades.

Three different adaptation modes are modelled in this system; (i) when to adapt (or to move); (ii) what percentage of total shading area; and (3) which location on the façade to shade. Notably, the behavioural rules vary in complexity via input data and information throughout the decision-making process. The interaction behaviour between the classes and different design parameters are identified and transformed into kinetic operation. Notably, the behavioural rules vary in complexity via input data and information throughout the course of decision-making. The collaboration behaviour between the classes and design constraints are recognised and converted into kinetic operation. The hierarchy of these modules is established and applied by synchronising communications with and controls of the others, as a whole. Figure 6.27 illustrates the framework of these classes and the established hierarchies among them.

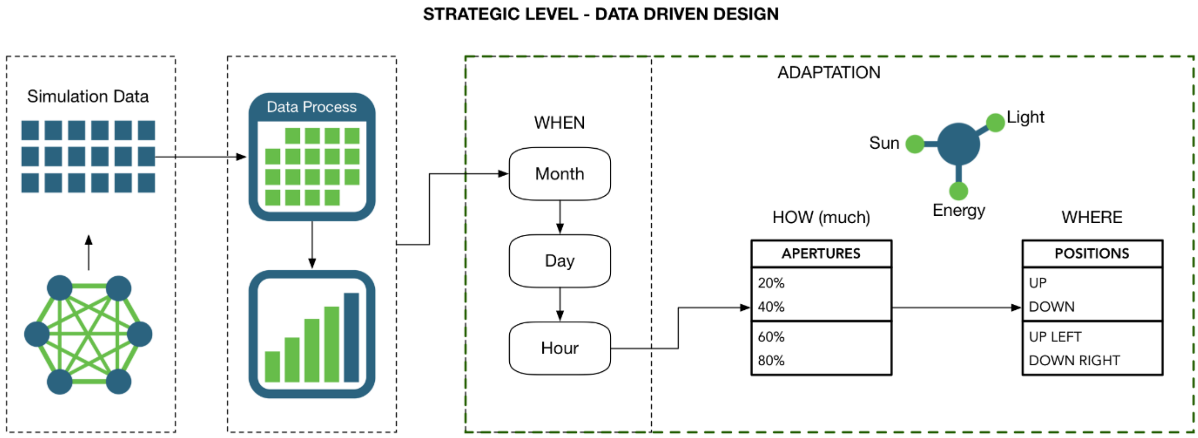
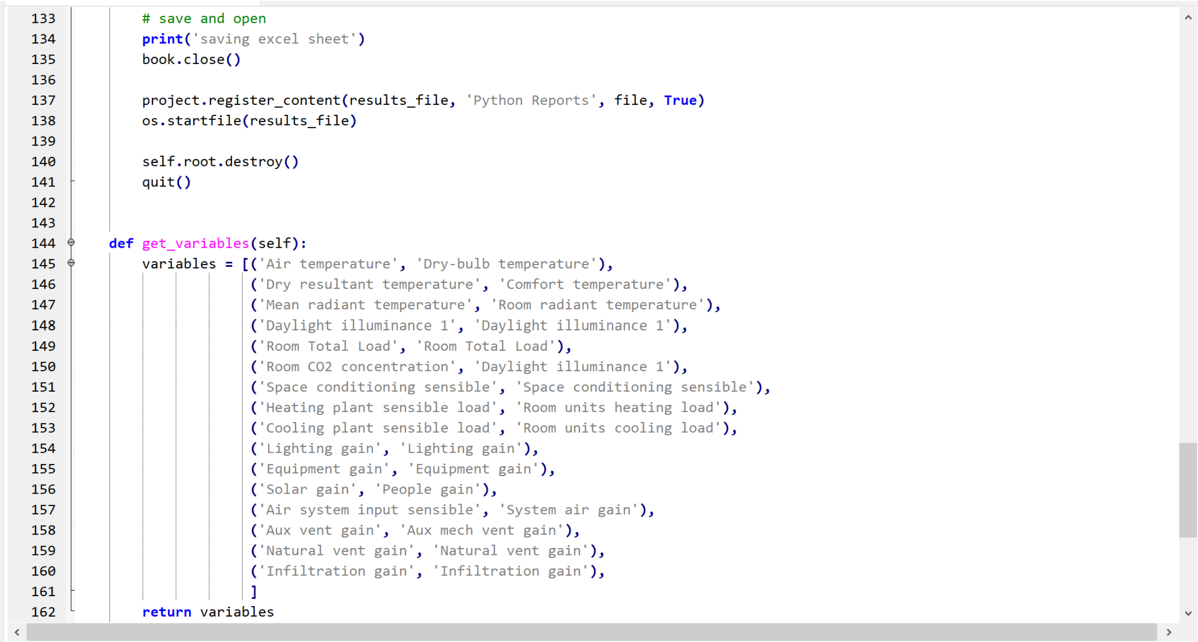


Figure 6.31 Adaptation strategy for façade shading device. (Source: Author).

Before getting to the adaptation stage, an important part of the process needs to be undertaken, the simulation process, which will be discussed in detail in the next chapter. The simulation results provide crucial data of optimal shading configurations, including all data of when, how and where the facade to react. This is defined as a data-driven process. In this research, simulation software used is IES-VE.

Figure 6.28 shows an extract of Python code used in the research to extract values of heating and cooling loads for weekdays working hours and save them in the form of Microsoft Excel spreadsheets. Use of this code gives ease for exporting data because it can run multiple times as a code, straight away and simple, with high accuracy and speed. It's superior to the conventional way to export data as users do not have to go deep into the energy model file. It works in the same way that VP does in BIM.



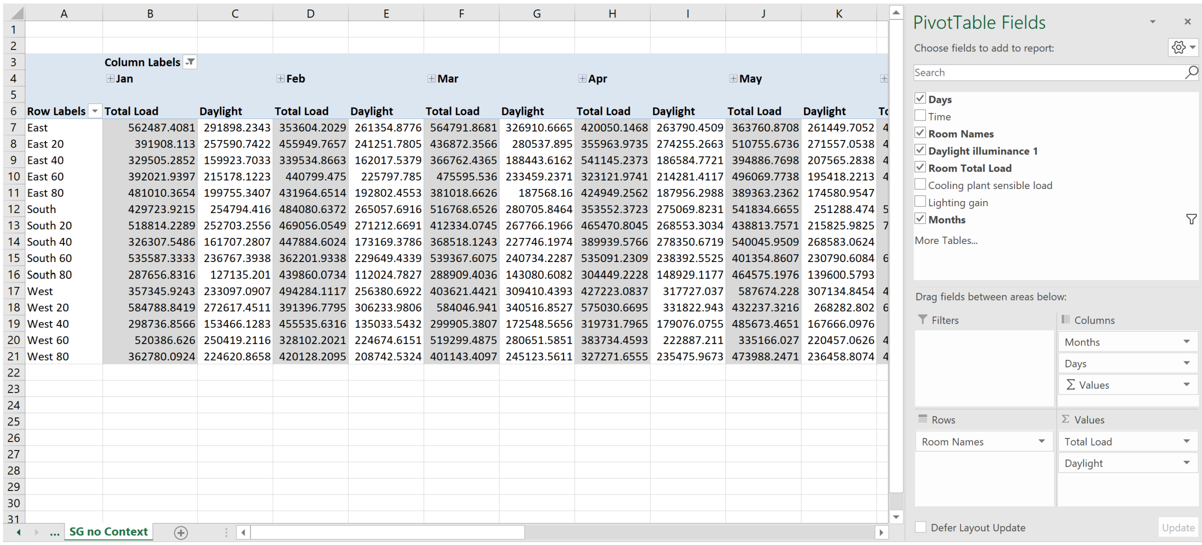
```python
        # save and open
        print('saving excel sheet')
        book.close()

        project.register_content(results_file, 'Python Reports', file, True)
        os.startfile(results_file)

        self.root.destroy()
        quit()


    def get_variables(self):
        variables = [('Air temperature', 'Dry-bulb temperature'),
                     ('Dry resultant temperature', 'Comfort temperature'),
                     ('Mean radiant temperature', 'Room radiant temperature'),
                     ('Daylight illuminance 1', 'Daylight illuminance 1'),
                     ('Room Total Load', 'Room Total Load'),
                     ('Room CO2 concentration', 'Daylight illuminance 1'),
                     ('Space conditioning sensible', 'Space conditioning sensible'),
                     ('Heating plant sensible load', 'Room units heating load'),
                     ('Cooling plant sensible load', 'Room units cooling load'),
                     ('Lighting gain', 'Lighting gain'),
                     ('Equipment gain', 'Equipment gain'),
                     ('Solar gain', 'People gain'),
                     ('Air system input sensible', 'System air gain'),
                     ('Aux vent gain', 'Aux mech vent gain'),
                     ('Natural vent gain', 'Natural vent gain'),
                     ('Infiltration gain', 'Infiltration gain'),
                     ]
        return variables
```

Figure 6.32 Extract from a computer programme for the export of simulation data from IES to Excel. (Source: Author).



	Column Labels									
	Jan		Feb		Mar		Apr		May	
Row Labels	Total Load	Daylight	Total Load	Daylight	Total Load	Daylight	Total Load	Daylight	Total Load	Daylight
East	562487.4081	291898.2343	353604.2029	261354.8776	564791.8681	326910.6665	420050.1468	263790.4509	363760.8708	261449.7052
East 20	391908.113	257590.7422	455949.7657	241251.7805	436872.3566	280537.895	355963.9735	274255.2663	510755.6736	271557.0538
East 40	329505.2852	159923.7033	339534.8663	162017.5379	366762.4365	188443.6162	541145.2373	186584.7721	394886.7698	207565.2838
East 60	392021.9397	215178.1223	440799.475	225797.785	475595.536	233459.2371	323121.9741	214281.4117	496069.7738	195418.2213
East 80	481010.3654	199755.3407	431964.6514	192802.4553	381018.6626	187568.16	424949.2562	187956.2988	389363.2362	174580.9547
South	429723.9215	254794.416	484080.6372	265057.6916	516768.6526	280705.8464	353552.3723	275069.8231	541834.6655	251288.474
South 20	518814.2289	252703.2556	469056.0549	271212.6691	412334.0745	267766.1966	465470.8045	268553.3034	438813.7571	215825.9825
South 40	326307.5486	161707.2807	447884.6024	173169.3786	368518.1243	227746.1974	389939.5766	278350.6719	540045.9509	268583.0624
South 60	535587.3333	236767.3938	362201.9338	229649.4339	539367.6075	240734.2287	535091.2309	238392.5525	401354.8607	230790.6084
South 80	287656.8316	127135.201	439860.0734	112024.7827	288909.4036	143080.6082	304449.2228	148929.1177	464575.1976	139600.5793
West	357345.9243	233097.0907	494284.1117	256380.6922	403621.4421	309410.4393	427223.0837	317727.037	587674.228	307134.8454
West 20	584788.8419	272617.4511	391396.7795	306233.9806	584046.941	340516.8527	575030.6695	331822.943	432237.3216	268282.802
West 40	298736.8566	153466.1283	455535.6316	135033.5432	299905.3807	172548.5656	319731.7965	179076.0755	485673.4651	167666.0976
West 60	520386.626	250419.2116	328102.2021	224674.6151	519299.4875	280651.5851	383734.4593	222887.211	335166.027	220457.0626
West 80	362780.0924	224620.8658	420128.2095	208742.5324	401143.4097	245123.5611	327271.6555	235475.9673	473988.2471	236458.8074

Figure 6.33 Excel data processing. (Source: Author).

Data processing and manipulation are vital in the macro framework. The process translates raw data into information which will then be used in VP codes to feed the actions. Figure 6.29 reveals the capability of KiSS system in handling and managing rich data gained from extensive simulations, between its sub-system using quantitative data processing methods, which will be explained explicitly in Chapter 7.

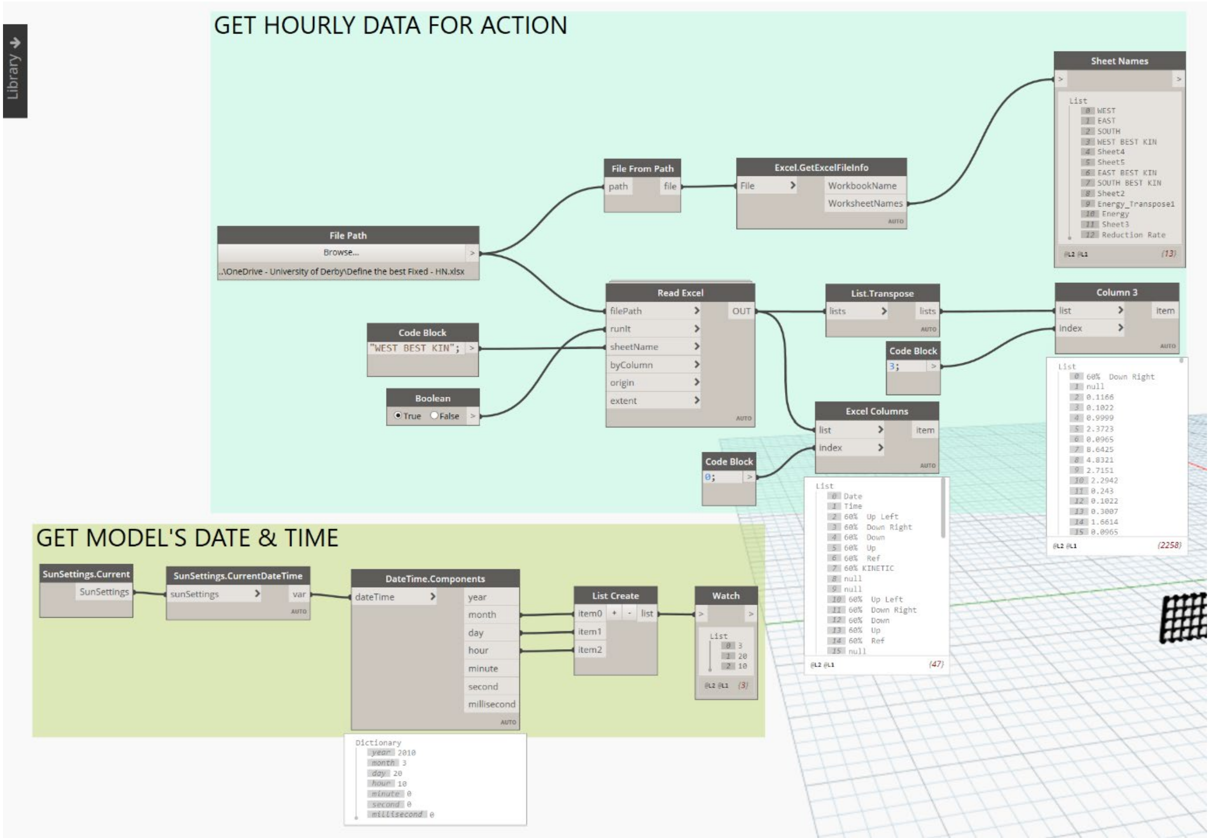


Figure 6.34 Link processed data with visual programming (Dynamo). (Source: Author).

As depicted in Figure 6.30, current sun settings, date and time of the virtual model are calculated via Dynamo nodes. A workflow of importing Excel spreadsheet with data from IES VE simulation and reading from it is also programmed; Dynamo can now process the data in the form of columns, in a similar way that Excel does. It enables the virtual shading system to react hourly over the whole year, which includes 2250 hours after removing non-functioning time such as weekends and holidays. For example, it knows that at a given time, say 3 pm, on the summer solstice day, the façade aperture must be 40%, and the position of shading is on the top right corner as the sun vector is on that direction. This new kind of twofold adaptive operation is clarified in the next section.

6.3.3 Shading Ranges and Positions

A crucial step in the KiSS framework involves developing a computational process that drives the shading kinetic. As determined in the section of adaptive operation, it is the major concept introduced in this thesis, in which, both of shading ranges (apertures) and positions are simultaneously calculated; as a result, the twofold dynamic shading system is termed as an *adapt-by-moving shapes* system.

The novelty of this kinetic lies in the term itself. It is new in the sense that the conventional systems have been intensively documented in the literature as a passive dynamic. In fact, these systems mostly are louvres in the form of vertical, horizontal and folding fins. For example, Shan and Junghans (2015) proposed adaptive radiation principles, Acosta et al. (2016) and Xue et al. (2019) purported optimisation of window-to-wall ratios. In these works, several windows on various locations and sizes were chosen, and the facades were optimised by varying parameters of glazing U-values, depth and angle of shading elements. Other popular solutions are movable solar shading (Nielsen et al., 2011; Uribe et al., 2019; Yao, 2014), switchable glazing (Baetens et al., 2010; Liu et al., 2014), wall-integrated phase change materials (Kuznik et al., 2011), tilting-blinds and opening-shutters (Chen and Huang, 2016; Gagne and Andersen, 2012). Their kinetic merely is rotation – changing angles of the fins around their axes, vertically or horizontally, in order to create distinct opening ratios (apertures, in this research), but these fins' body themselves never move, which makes them simple one-fold kinetic. The critical difference of the proposed system is the 'where' (or positions) (for its strategy, see Figure 6.29), acting as a two-fold external decision-making commander capable of activating the kinetic mechanisms following feedback rules. Indeed, it aggressively moves a part of its body into a position previously decided by simulation datasets (see Chapter 7) adapting to both solar altitudes and azimuth, at the same time. These moves allowing both direct sunlight and diffuse skylight to enter the space with under control intensity, increasing both daylight levels and visual comfort.

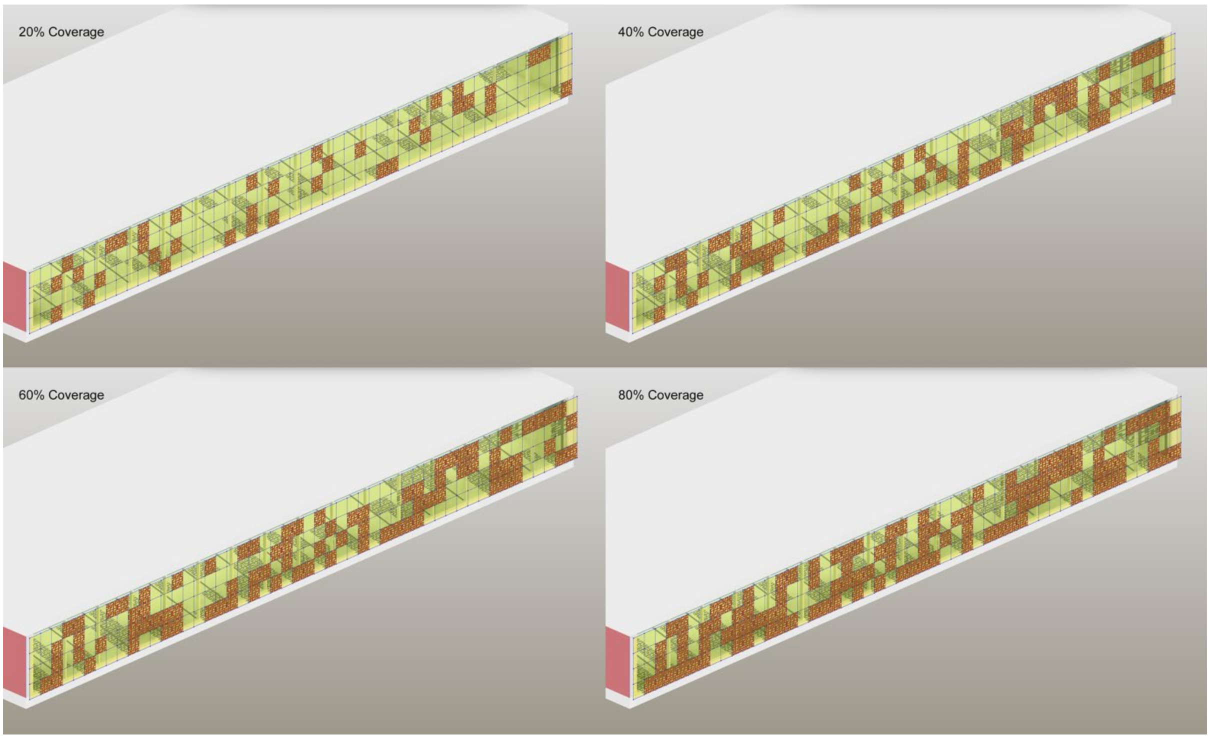


Figure 6.35 Shading apertures in randomly distributed compositions. (Source: Author).

In order to achieve such complex dynamics, several tasks need to be done in the computation. Firstly, a grid-based structure is created to handle lower-level patterns – the façade panels. This structure is the same as the structure analysed previously for chosen patterns. In this study, most patterns have a square grid structure. Triangle and rectangle grids can be applied in the same manner. Size of the grid is defined by designers, depending on the overall size of the façade. The base panel in this research is a 600 x 600 mm square. Figure 6.31 shows different shading apertures (20%, 40%, 60% and 80%) over a grid consisted of 4 x 30 square panels.

Secondly, information of global aperture of the entire façade is required; for example, 50% of the façade needs to be shaded. Thirdly, information about shading position is needed, for instance, the right side of the façade. A number of panels needed to make 50% are calculated as $N = 50\% * S_G$. Where N is the number of panels, S_G is total panels of the grid. Apply to this case: $N = 50\% * (4*30) = 60$. Thus, 60 panels are put into the right side of the façade (see Figure 6.32-right). Their locations are user-defined; thus, can be flexible or fixed.

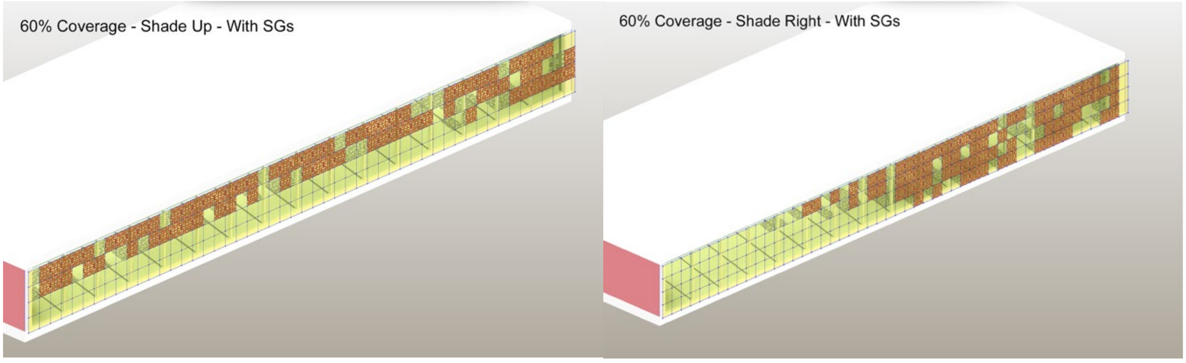


Figure 6.36 Two shading positions of 60% aperture - up and right. (Source: Author).

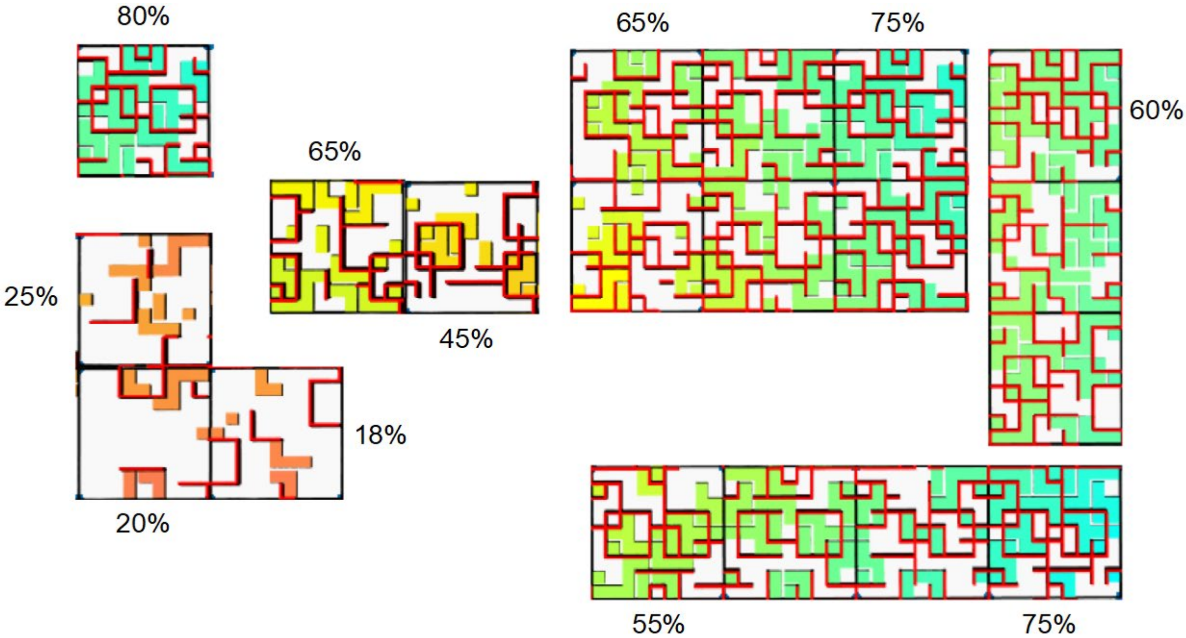


Figure 6.37 Visual programming of shape grammars to represent different percentages of shading apertures on local panels. (Source: Author).

Finally, the local panels are then created by the aperture calculation process, which has been defined in the previous section. Again, they are controlled under design intention. In fact, all panels can either have the same aperture of 50% or different apertures calculated to make up 50%. Particularly, Figure 6.33 proves the aggressiveness and flexibility of KiSS facades, showing examples of different, random apertures, from 18%, 45% to 80%, calculated so that the average of a matrix of 60 distinct percentages achieves an exact 50%. Again, such computation capability and arrangement complexity can only be done by a generative process.

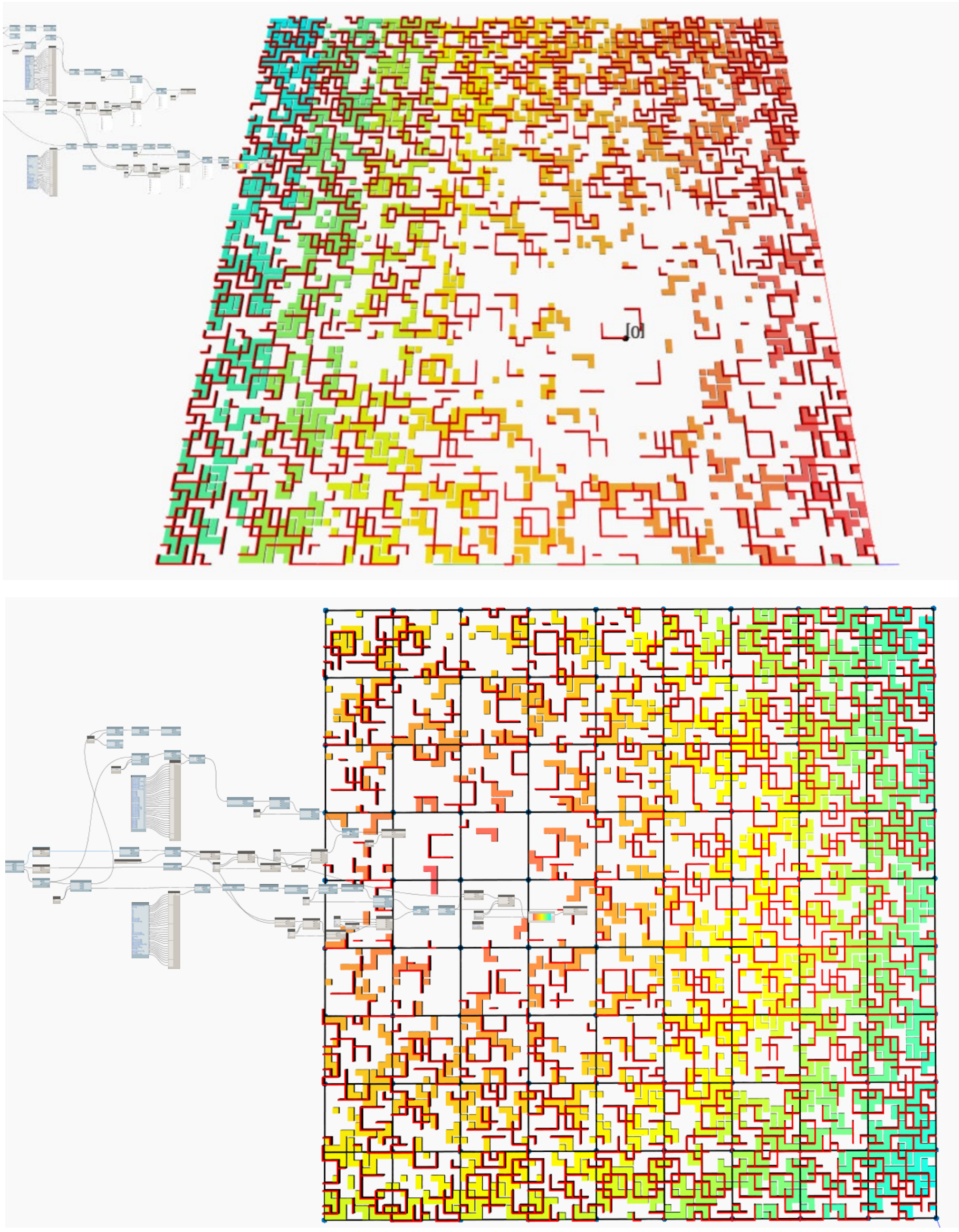


Figure 6.38 Possible shading positions in association with shading apertures. (Source: Author).

Designs of KiSS facades can be extended to a new degree of kinetic, which is depicted in Figure 6.34. Apertures of local panels gradually change in the ways which smoothly increase or decrease their shading percentages. For example, a certain area of the façade is decided to be more transparent than other areas, letting more natural light to enter the space. In the picture, it is around the middle area. Specifically, from a system-defined central panel, with 0% shading, happening as an attractor point, adjacent panels' apertures are calculated to be steadily getting bigger until reaching a maximum of 80% on corner parts. All panels together will eventually make up an average of, for instance, 65%. This organic kinetic reflects a biological adaptation observed in nature, especially in plants and trees, where a number of leaves and branches alongside their sizes are set up to absorb as much daylight as they can; the longest and biggest branches are always directed to the brightest area.

6.4 System Visualisation

Visualisation has always been an important task in design. To demonstrate aesthetic cultural metaphor and flexible, adaptive ability of KiSS's productions, several 3D images of an office building are rendered and depicted in Figure 6.35 below. Due to time limitation, only several shading positions are involved. The examples show the facades are more open at bottom-right corner bottom-left corner while being opaque in the middle area.

Figure 6.39 Artistic impression - 3D rendered image of a façade composition. (Source: Author).

6.5 Chapter Summary

Developed upon the methodology of System Development by Nunamaker et al. (1990) this chapter has demonstrated that a new generation of traditional Vietnamese patterns has been successfully created by the proposed Kinetic Solar Shading (KiSS) framework, which consists of sub-frameworks such as BIM-based generative system (BGS) and BIM-integrated simulation methods. Several main conclusive points can be made, as follows:

1. The mixed-methods approach applied within System Development has been practically adaptive, leading to deductive implications of consolidation of qualitative and quantitative methods in the form of sub-frameworks, which represent the four stages of KiSS, including Conceptual development of design schema, Visual programming of design schema, Sustainable Design Simulation and Design Validation and BIM, with stage 3 - Sustainable Design Simulation will be described in detail in the next chapter due to its entanglement.
2. Conceptual development of design schema has harnessed the two most significant power of shape grammars (SG) – analytic and generative. Importantly, analytical grammars have been performed under the notion of the anticipated emergence of shapes, while generative SG have been executed under the concept of unanticipated emergence, which is mostly overlooked in the literature. Based on a set of simple rules and shapes, these combinations have helped generate a broad set of innovative yet intricate pattern designs and established a solid foundation for the computational stage.
3. Visual programming of design schema has been done in the BGS workflow, in which, data and information from the conceptual design schema are parameterised, and shapes and rules of grammars are reproduced in the form of visual codes of attributes and algebraic multiplications.
4. Design Validation is a crucial part of KiSS system and also the most significant success of the framework. Shading apertures and positions have been explicitly explained by means of algebraic expression for the purposed of enhancing daylight quantity and energy performance of the shading devices. Most importantly, as a result, it has introduced a new kinetic concept of *adapt-by-moving shapes*.

In summary, the framework supports critical reasoning, rational reflection, deductive and inductive thinking, helping to realise the kernel structures of artefacts which lead to a generation of creative solutions in order to serve meaningful purposes of sustainable design.

CHAPTER 7: SYSTEM ANALYSIS AND VALIDATION

"A great building must begin with the unmeasurable, must go through measurable means when it is being designed and in the end must be unmeasurable".

- Louis Khan

7.1 Climate-based Daylight Modelling

Daylight illuminance (DL) in buildings is a term that refers to dynamic, direct and indirect sunlight illuminance levels, both in intensity and spatial distribution, caused by the interaction between the sun and the sky, building form, location and material physical properties. In earlier years of building performance analysis, commonly used method in simulation was based on the Daylight Factor (DF), which referred only to the diffused skylight under the basic sky model of the Commission Internationale de l'Eclairage (CIE) – the Standard Overcast Sky, and did not comprise the contribution of direct sunlight (Mardaljevic et al. 2009).

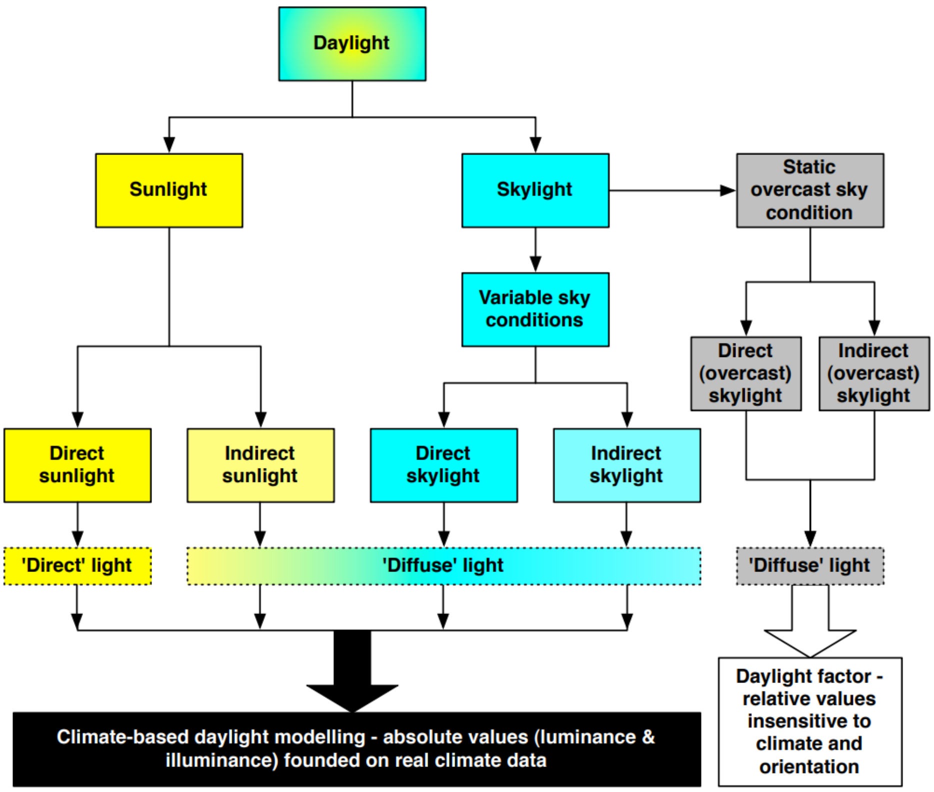


Figure 7.1 The mechanism of daylight and its relation to daylight factor and CBDM methods (Mardaljevic, 2006).

Later developments concentrated on the refinements of enhanced simulation models by means of the better computational ability to improve the approach to daylight assessment.

Climate-responsive data has been introduced, adding time-varying attributes to the process. Nabil and Mardaljevic (Azza Nabil and John Mardaljevic, 2006) reported on Climate Based Daylight Modelling (CBDM), the concept of which is now broadly used.

CBDM comprises of the dynamic calculation of daylight levels in a design space, with a cumulative year results based on the hourly analysis, using sky models generated from standardised hourly weather data, built for a given project location (see Figure 7.1). Thus, designs concerning changes in natural light availability such as kinetic shading systems positioned for employing direct sunlight are now ever more applicable. In fact, the design process is now prediction of where and when and the designs to perform, and evaluation of how well they perform regarding daylight availability and solar gains. Consequently, a thoughtful design process employing CBDM will result in exclusive solutions that are unique to the project location.

7.1.1 Daylight Performance Metrics and Sustainable Codes of Practice

In recent times there has been growing demand around the world for more sustainable design practice, with numerous countries introducing their own codes of practice and standards. One of the earliest codes for sustainable design, UK's BREEAM and US's LEED, are used worldwide for building compliance but also as models for other rating systems being developed across the world. These codes support several daylight performance metrics (see Table 7.1), with each metric having its own advantages and limitations. Most used are Daylight Autonomy (DA) (Reinhart, 2002; Reinhart et al., 2006), Useful Daylight Illuminance (UDI) (Gugliermetti and Bisegna, 2005), Continuous Daylight Autonomy (cDA) (Reinhart et al., 2006), and Spatial Daylight Autonomy (sDA) (IESNA, 2012).

Table 7.1 Daylighting metrics.

Daylighting metrics	Sky Types	Lower limit	Upper limit	Calculation Period
Daylight Factor (DF)	CIE Overcast	2-5%	NA	Annual & Specific time
Single Point in Time Illuminance (SPT)	All	500 Lux	NA	Specific time
Daylight Autonomy (DA)	All	500 Lux	NA	Annual

Continuous Daylight Autonomy (cDA)	All	500 Lux (partial count for points below)	NA	Annual
Useful Daylight Illuminance (UDI)	All	100 Lux 300 Lux	2000 Lux 3000 Lux	Annual
Spatial Daylight Autonomy (sDA)	All	the percentage of space area that obtains a minimum of 300 lux for at least 50% of the annual working hours.		Annual
Annual Sun Exposure (ASE)		the percentage of space area that gets minimum 1000 lux for at least 250 working hours per year.		Annual
Daylight Availability	All	500 Lux	Provide warning when an oversupply of daylight (10 times target illuminance) is reached for at least 5% of the working year.	Annual
Daylight Glare Probability (DGP)	All	Imperceptible: (DGP < 35%). Perceptible: (40% > DGP ≥ 35%) Disturbing: (45% > DGP ≥ 40%) Intolerable: (DGP ≥ 45%)		Annual & Specific time

Three of these metrics are used in LEED v4: UDI, sDA and ASE for daylight performance evaluation (Jakubiec and Reinhart, 2011), with two of those used in this research; UDI and sDA.

7.1.1.1 Useful Daylight Illuminance – UDI

Generally, an achieved UDI is a long-term, local metric defined as the annual amount of illuminances over a defined work plane that lies in an array of values considered useful for officers (Nabil and Mardaljevic, 2006). This useful range is commonly used after reports of a survey on occupant reactions and behaviours conducted in non-residential and large office buildings (with manually functioned shading devices) in which a severe problem is high levels of daylight cause glare on display devices, such as computer screens, and undesired solar gains.

Four UDI indexes were introduced by Mardaljevic et al. (2009):

- UDI fell-short (UDI-f) if DL < 100 Lx
- UDI supplementary (UDI-s) if 100 ≤ DL ≤ 300 Lx
- UDI autonomous (UDI-a) if 300 ≤ DL ≤ 3000 Lx
- UDI exceeded (UDI-e) if DL > 3000 Lx

The suitable daylighting strategy is referred to as one in which a significant spatial coverage lies in the range of UDI-a (300–3000 lux), whilst percentages of UDI-f and UDI-e are relatively small. Additionally, LEED v4 requires that illuminance levels are between 300 lux to 3,000 lux at two times - 9 a.m. and 3 p.m., both in clear sky condition, on the equinox days, for the 75% regularly occupied area.

7.1.1.2 Spatial Daylight Autonomy - sDA

The term Daylight Autonomy (DA) was officially coined by Reinhart and Walkenhorst (Reinhart and Walkenhorst, 2001) as the percentage of annual working hours within which a minimum illuminance threshold is met only by the daylight. The definition of DA is not accompanied by a specified threshold value; Olbina and Beliveau (Olbina and Beliveau, 2009) suggest setting the target at 500 lx. LEED v4 requires that 55% (1 point), 75% (2 points), or 90% (3 points) of regularly occupied space must receive 300 lx in 50% annual occupied time.

7.2 Building Performance Simulation

CBDM has been linked with the dynamic thermal simulation model (DSM); a number of researchers have demonstrated that daylight distribution has been added to prevalent energy simulation tools, for instance, EnergyPlus and IES VE (Carroll and Hitchcock, 2005; Janak and Macdonald, 1999).

7.2.1 Simulation Framework – CBDM and DSM

The main framework for simulations in this research is shown in Figure 7.2. Firstly, in order to carry out simulations of building performance, a process, from accessing data of the BIM model of the façade shading system design to exporting it to an energy analytical model, needs to be developed. The built environment data includes building/physics data, for example, glass transmittance and external wall U-values, and environmental data, such as location and weather data. The energy analytical model is stored in the format of gbXML (or green building XML) – a 15-year-old industry-standardised schema for distributing building energy information between different building design tools, so that major applications in the field can exchange project information regardless of the software vendor platform.

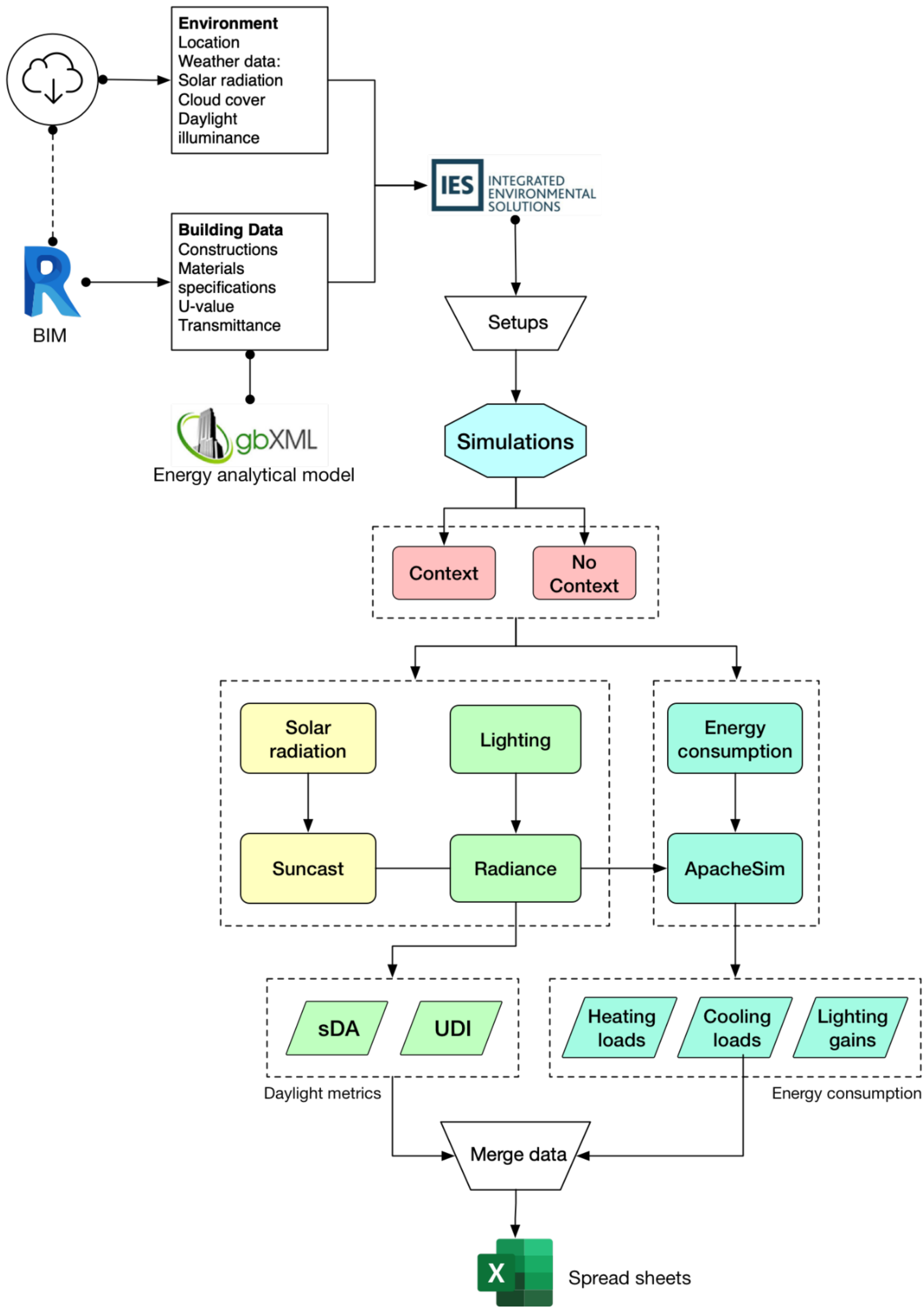


Figure 7.2 Simulations framework proposed in this research. (Source: Author).

In this research both LEED and BREEAM approved simulation tool – IES VE (Virtual Environments) has been used. IES is a whole building performance simulation tool which recognises the energy building model information in a different way a BIM software does. Indeed, an energy model does not represent all geometrical information of building but only aspects of geometry that are important for the purposes of the analysis. In this context, the abstraction, via levels of detail, is equivalent to the process of making scaled architectural models. According to Dunn (2010), it means '*taking away any unnecessary components or detail that will not aid the understanding of the design being communicated*'. Thus, VE requires gbXML to take BIM data and convert it into a building energy model (BEM). After that, an additional setup is required as users must prepare BEM for simulation by ensuring the accuracy of location and weather data, occupancy schedules, thermal templates and HVAC allocation, prior to the deployment of simulation. In traditional CAD-based procedure, designers need to create such a BEM model manually, from imported CAD drawings; this is not a straightforward process and practically speaking can be time-consuming.

Simulation is then based on dynamic simulation model (DSM) (Holland, 2000) which calculates dynamic heat transfer and light levels, every hour, over the period of the whole year. Theoretically, it involves: (i) defining a real-world context at time 't', abstracting it and transferring the definition in the form of data into model at that time, and (ii) calculating in 't+1', and converting the results into real-world context and interpreting their meaning into virtual model at time 't+1.'

The contextual aspects that affect the design and require set up are as follow:

(i) global context: climatic weather data for selected locations, including the impact of predicted climate change;

• local context: solar radiation, daylight illuminance, site configuration, overshadowing by the existing surroundings, etc.

Once above are set, simulations are performed for solar radiation and daylight levels. These two types of analysis are interchangeable, as each can be done before or after the other. However, Suncast (solar radiation) is undertaken first since it provides an initial understanding of external impacts, such as surrounding buildings and landscape and the shading device, on the defined space. The next step is IES VE Radiance (lighting analysis); it calculates hourly data for luminance, illuminance and most importantly, annual daylight metrics - sDA and UDI - for advanced data processing in this research. The workflow follows climate-based daylighting simulations (CBDM). Additionally, when the analysis of solar radiation and daylight levels is completed, the output data is linked to ApacheSim simulation (dynamic thermal simulation engine based on the mathematical modelling calculations of the building heat transfer).

Once the simulation is completed, the results are accessed through IES VistaPro, where numerous type of reports can be produced, and data can be visualised in the form of charts or tables.

The output results extracted for this research are:

Daylight Simulation

- annual natural daylight availability, in particular;
- Useful Daylight Illumination – UDI
- Spatial Daylight Autonomy – sDA

Thermal Simulation Related

- heating and cooling loads.
- internal heat gains, i.e. sensible and latent heat
- electric lighting gains;

Further detail will be discussed in Section 7.4 – Dynamic Simulation.

7.3 Simulation Input Data

7.3.1 Climate Characteristics of Vietnam

Vietnam has a S-shaped territory, spreading from 8°30'N to 23°22'N and has a tropical monsoon climate (Vietnam Ministry of Construction, 1985). It has all types of terrain, such as jungle and highland, peaks and rivers, seaside and lagoons. Its geography is complex and fragmented, slowly falling in levels from Western highlands to Eastern shores. The Vietnamese Building Code considers the country having two dominant climatic regions:

- The North (above 16°N latitude) - a humid tropical monsoon climate with considerably cold winters.

- The South (below 16°N latitude) - both tropical monsoon and savannah climate including a rainy season (May - October) and a dry season (November - April).

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Figure 7.3 Map of Vietnam, including positions of Hanoi, Hue and Saigon (Ho Chi Minh).

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Figure 7.4. Koppen-Geiger climate classification map for Vietnam (Source: Left: Peel et al., 2007; Right: Beck *et al.*, 2018).

More recently, the work of Peel et al. (Peel et al., 2007) and a Nature's research of Beck et al. (2018) categorise Vietnamese climate in three key distinctive climate zones, unevenly distributed along the country (see Figure 7.4): (i) Tropical monsoon (equatorial monsoon - Am) in the Centre and (ii) tropical savannah (equatorial savannah - Aw) in the South, covering about two-thirds of the country's area. The rest is the territory from around Hanoi goes all the way up North, is temperate with dry winter and hot summer (Cwa).

Almost the entire country is subject to seasonal monsoons that produce significant rainfall in all parts. Its temperature varies between 12°C and 34°C; the annual mean temperature is around 21°C. The North has four seasons with a relatively cold winter as the temperature can be as low as 6°C and a hot summer with temperature may reach 40°C. The Central part share similarities more with the North rather than with the South. It is the most disaster-vulnerable zone, stretching across a slim terrestrial belt with the longest width of 60 km. The South part temperature is between 21°C - 34°C, with two different seasons, a rainy season (May – November), and a dry season (December – April). Vietnam has sunshine hours from 1100 to 2500 hours (see Table 7.3) per year. The relative humidity is mostly above 75%, which is typical for this region. Rainfall is high across the country as annual precipitation is more than 1000 mm, in all regions (Ly et al., 2010).

7.3.2 Weather Data for Hanoi, Hue and Saigon

Dynamic simulation method appeared first in the 1950s (Burnand, 1952), but it had to wait until the energy crisis of the 1970s to be officially defined and applied in research concerning building energy performance (Newton et al., 1988). Weather data was initially accessible in the form of specialist software packages but later became 'weather files', in the form of typical weather years, generated by historic monitoring at the airports. Furthermore, according to the International Building Performance Simulation Association's reports, with the most popular thermodynamic simulation engine at the time being EnergyPlus, has led to the spread of its native weather format – the '.epw' file (Energy Plus Weather). These text-based CSV files contain hourly weather variables for a given location over a year time.

Recently, climate data has been developed to be climate-adapted; it is now more local-based, city-specific and more accurate in representing real-world conditions. It typically contains the following weather data, gathered on at least hourly basis (8760 hours of data in each file):

- Air temperature (dry bulb)
- Dew point temperature
- Wet-bulb temperature
- Global horizontal radiation
- Diffuse horizontal radiation
- Direct beam radiation
- Wind direction and speed
- Relative humidity
- Absolute humidity
- Cloud cover
- Rainfall
- Illumination levels

Table 7.2 Geographical and climatic information of chosen Vietnamese cities.

Location	International climate zone	Koppen-Geiger Class	Latitude	Longitude	Elevation (m)
Hanoi	Temperate, dry winter, hot summer	Cwa	21.22N	105.81E	12
Hue	Tropical, monsoon	Am	16.46N	107.60E	8
Saigon	Tropical, savannah	Aw	10.50N	106.40E	19

Table 7.3. Cooling season of each city.

City	Climate	Average annual temperature			Annual sun hours	Coolest month	Warmest month	Cooling seasons
		Min	Max	Average				
Hanoi	Humid subtropical	21.0°	27.0°	24.0°	1167	January	July	May – October
Hue	Monsoon	22.0°	29.0°	25.0°	2135	January	July	March – August
Saigon	Tropical savanna	23.0°	32.0°	28.0°	2299	December	April	March - October

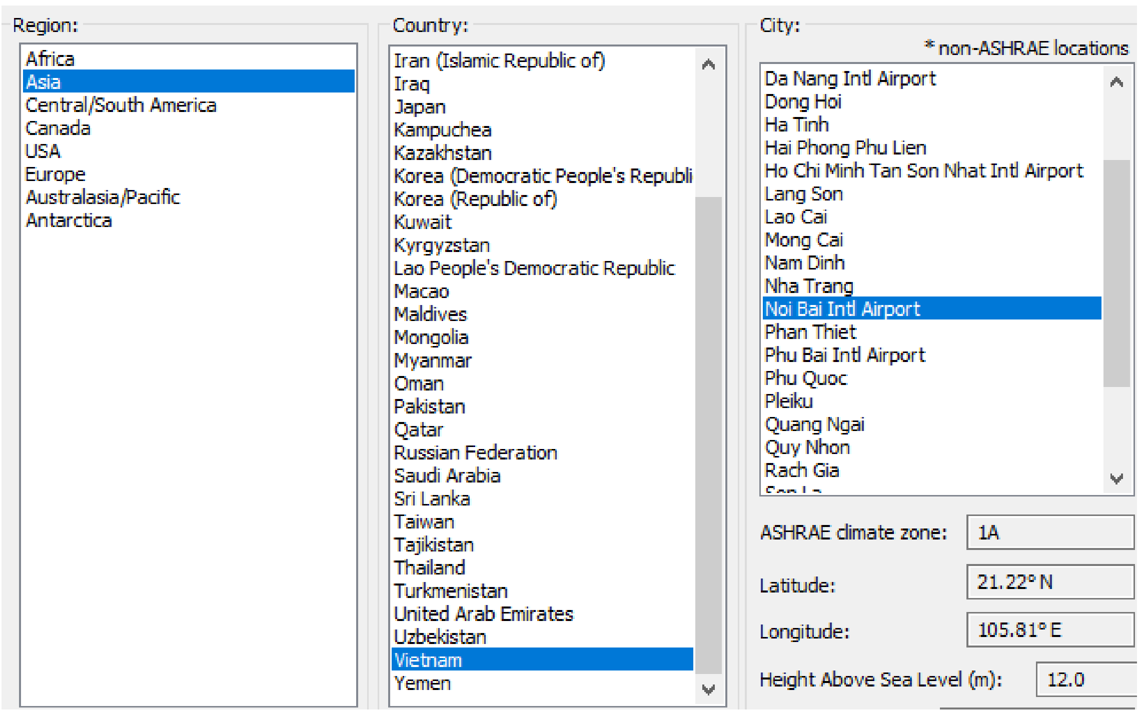

Figure 7.5 IES VE's APLocate to define project location.

Solar Radiation:
The south orientation has the longest sun exposure since it sees the sun almost all day long; from mid-morning to mid-afternoon (approximately six-hour-long). The east and the west side are warmed up directly by the sun for approximately three to four hours. However, interestingly, this often does not make the south the side with highest heat gains because the sun's altitudes on the south side are significantly higher than that on the east and west, meaning there is less direct sunlight falling on the south side than that on the other two. In other words, there is more direct sunlight on the east and west sides where the sun's altitude is low, and there is more diffuse light entering at the south side.

Table 7.4. Average monthly statistics for direct and diffuse solar radiation in the three cities (W/m^2).

	Direct Radiation			**Diffuse Radiation**		
	Hanoi	Hue	Saigon	Hanoi	Hue	Saigon
Jan	145	234	443	117	198	180
Feb	70	253	436	133	198	202
Mar	90	209	431	151	252	216
Apr	138	310	398	207	216	223
May	254	387	319	212	207	238
Jun	247	379	294	216	195	235
Jul	257	417	288	217	185	238
Aug	187	393	331	248	204	236
Sep	342	323	315	186	229	247
Oct	323	218	346	167	228	230
Nov	297	207	384	169	213	206
Dec	288	177	430	131	198	179

7.3.3 Case Study

7.3.3.1 Geometry and Construction input data

The case study used for this research is a square office sized 30 m x 30 m, situated due south on the site in Hanoi, Hue and Saigon, whose specific locations are listed in Table 7.2. It is an open plan office with four perimeter zones, facing North, East, South and West; and a central inner court zone (see Figure 7.6). In order to effectively simulate effects of shading devices at each of three orientations – east, south and west – the space is divided diagonally to ensure that solar gains correspond to relevant elevations that re being analysed. Thus, shading devices were placed on three sides of the building; east, south and west. The building enclosure construction is based on concrete masonry office space in ASHRAE Climate Zone 1A, where Hanoi, Hue and HCM are located (for more details, see Appendix D). Surrounding buildings are included to mimic an urban context, with two 10m x 10m x 10m buildings at each side, located 10m away from the building under simulation.

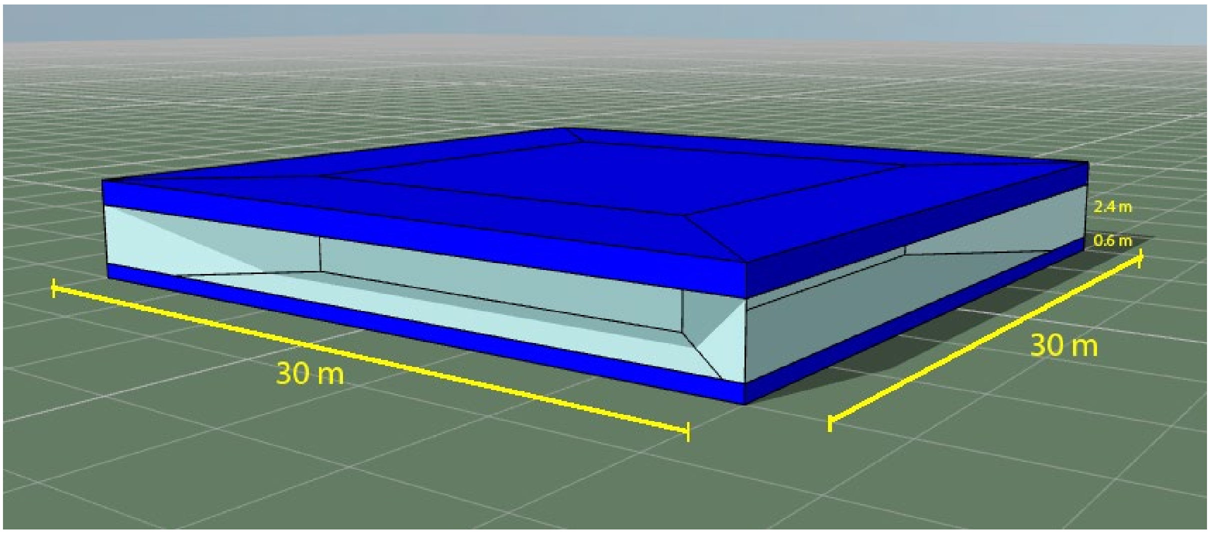

Figure 7.6 3D model of the case study, imported from BIM-based gbXML. (Source: Author).

Table 7.5 lists the construction data for the office space used in the energy model. These values are based on ASHRAE 90.1 2010 guidance. The floor-to-floor height is 3.0 m. The built-in facade has a 2.4m height glass curtain wall. Reflectance values for surfaces of ceiling, walls, and floor are 70%, 50%, and 20%, respectively (see Table 7.7).

Table 7.5. Building enclosure specifications.

	Material (from outside to inside)	Thickness (mm)	Height (m)
Floor	Concrete	101	-
	Carpet	5	
External wall	Sheathing	2	3.0
	Insulation (0.045 W/m K)	78	
	Blockwork	220	
	Gypsum board	13	
Glazing	-		2.4
Roof	Roof membrane	9	-
	Insulation (0.049 W/m K)	211	
	Metal decking	2	

Essential input data and physical material's properties for simulations are listed in Table 7.6 and Table 7.7. The cooling setpoint is 26 ºC, and the heating setpoint is 20 ºC.

Table 7.6. Key parameters used in the energy model of office spaces.

Energy model parameter	Value	Energy model parameter	Value
Wall U-factor (W/m2 K)	0.43 W/m^2 K	Lighting power density	10.76 W/m^2
Floor U-value	2.193 W/m^2 K	Equipment power density	10 W/m^2
Roof U-value	0.223 W/m^2 K	Ventilation rate	0.006 m^3/s - person
Glazing U-value	2.672 W/m^2 K	Infiltration rate	0.19 air changes/h
Cooling setpoint	26 ºC	Occupancy density	0.25 people/m^2 m
Heating setpoint	20 ºC	Occupancy schedule weekdays	9:00 AM-6:00 PM

The modelling and simulations are carried out with IES-VE (Integrated Environmental Solutions – Virtual Environment), a building performance simulation system supported by LEED and BREEAM. The base (reference) case has no external shading, and the proposed kinetic system apertures change from 20% to 80% of the total glazing area (in 10% increments).

Table 7.7. Materials physical properties for daylight simulations.

Building Component	Reflectivity	Visual Transmissivity
Walls and partitions	0.5	-
Ceiling	0.7	-
Floor	0.2	-
Shadings	-	-
External ground	0.2	-
Glass	-	0.8

7.3.3.2 Dynamic Operation Profiles

Before undertaking thermal simulations, HVAC system and thermal templates for space conditions must be set up. Operational profiles for occupancy, lighting and computers use are specified in APpro - profiles database, which includes daily, weekly and annual profiles. The operational profiles in this study are manually modified to be more flexible and adaptive to respond to external changes in illuminance and internal gains in occupancy and equipment.

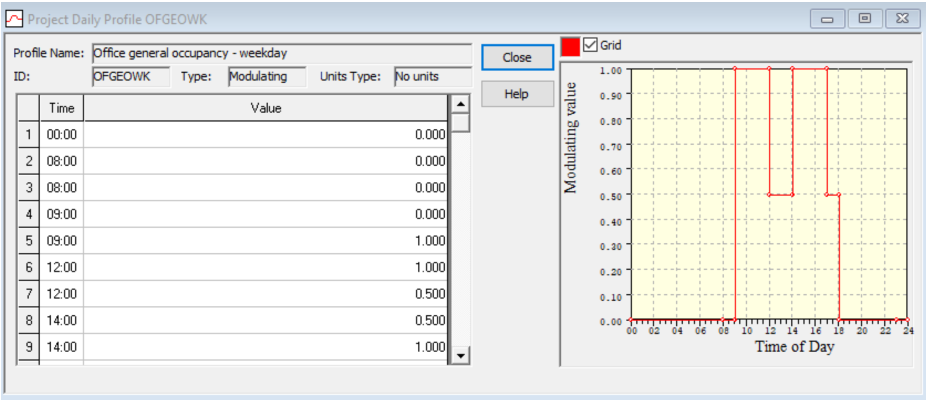

Figure 7.7 Occupancy schedule in weekdays. (Source: Author).

Daylight-sensitive switching assumes that artificial light is set to be turned on to compensate natural light levels when they fall below required illuminance levels. Hence, some lights will be turned on (or turned off), at certain positions in the office, depending on internal light intensity. To do so, indoor daylight levels are read by virtual sensors (see Figure 7.9) in the same way that real time monitoring studies work, with real physical sensors placed on a horizontal grid of working plane to obtain illuminance values. Importantly, VE has an effective cross-referencing mechanism to link both natural light levels and artificial lighting demands to the thermal simulation module.

Generally, artificial light levels are normalised to an array 0 to 1 with a dimming profile that has 0 corresponding to the lights being entirely off, and 1 to being fully switched on. For example, the standardised illuminance of artificial lights for all grid points of the office space is set at $AL_{standard} = 500$ lx; the light connected to a point will be completely switched off if the daylight sensor of that point shows daylight level above 500 lx ($DL \geq 500$ lx). If it is below this standard level, the dimming profile starts calculating the sum of DL and AL to 500 lx, such that artificial light level required could be calculated as $AL = 500 - DL$.

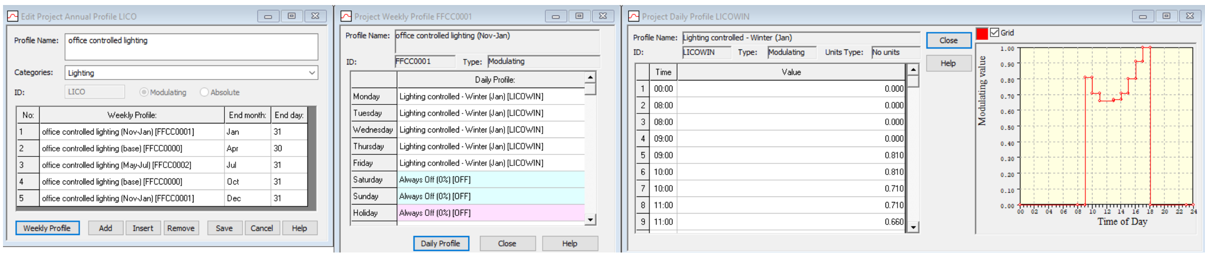

Figure 7.8 Three layers of lighting schedule, from annual, weekly to daily profiles. (Source: Author).

This dimming profile is vital in reducing lighting gains as it controls accurate lighting intensity using available daylight levels, hence minimising both the heat gains and consumption of electrical energy. Figure 7.8 shows an advanced dimming profile that contains four sub-profiles with illuminance levels obtained from weather data. Each seasonal profile has its own weekly to daily profiles built upon the given illuminance data. This master profile can be understood as an adaptable artificial lighting control system, based on the virtual sensor data (Figure 7.9).

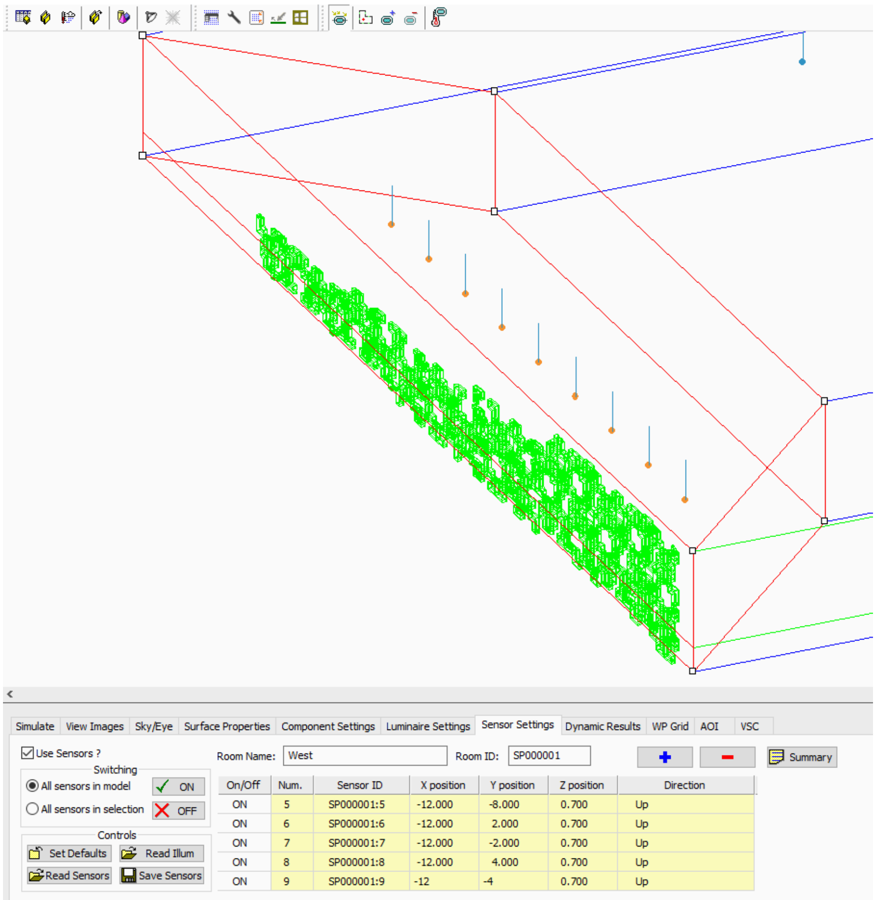

Figure 7.9 Daylight reading sensors placed in the workspace to link with thermal simulations. (Source: Author).

Users of the simulation are allowed to create a realistic grid of virtual sensors if needed, for example, 0.6m x 0.6m grid across 100m2 working plane. This will give more accurate results for evaluation, though it requires very high computing power.

7.4 Dynamic Simulation

IES VE, like other building simulation tools, is also a data presentation and management software (Attia et al., 2009). It shows simulation results in data sets, charts and diagrams and is able to present them in different ways that helps designers understand the building performance. Based on this simulation data, the post-simulation process can deploy validation and optimisation phases in the final quest for improved performance (Fig. 7.8).

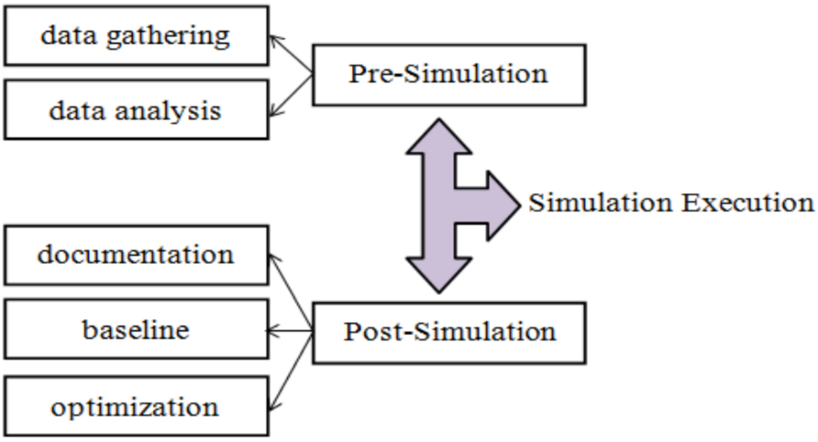

Figure 7.10 Framework for thermal simulations and analysis. (Source: Author).

Its simulation graphic user interface allows designers to simulate from an early, schematic-stage to a detailed construction analysis with fully specified lighting, HVAC systems and operational profiles.

As described in the last Chapter, this research proposes its own framework for generative design solutions; which, theoretically, could be produced in high numbers. Indeed, the shading aperture and position can be deployed in many configurations. However, it is not practically easy to create such number of BIM models and simulate all of them, as they can be very time-consuming and computer demanding. Dynamic thermal simulations and climate-based daylighting simulations take many parameters into account; thus, process requires powerful computers to simulate. The system framework in this research is hence built explicitly for "proof of concept" purposes, thus, a limited amount of design alternatives is produced and optimised.

In the first phase eight apertures of climate shading system are simulated, ranging from 0% (no shading) to 80%, in increments of 10%. Furthermore, case study is analysed in three specific locations, presenting three Vietnamese cities and three typical climates – Hanoi, Hue and Saigon, with their location specific weather data. Since the evaluation and validation process forms an important part of proposed research methodology, as stated in Chapter 2, the best 'fixed' façade shading configuration will be used as a benchmark for assessing and validating the effectiveness of the simulated kinetic shading device. In the second phase, a choice of competitive solutions closest to the 'best-fixed' scenario, will be further analysed, with five shading positions selected to seek for kinetic solutions that potentially could outperform the best-fixed case. It is expected that the dynamic shading system should demonstrate a noticeably higher efficiency in terms of both lighting and energy use.

7.5 Phase 1 – Finding the 'Best Fixed' Aperture Configuration

Optimising the shading device with energy saving purpose, i.e. to minimise heating and cooling loads and electrical lighting internal gains, whilst providing required daylight levels is not a straightforward process; rather, it could be a conflict resolving process. Cooling loads for example are interlinked with lighting gains. A low value of daylight levels, besides the obvious health and human comfort issues, could mean too much of additional internal gains due to electrical lighting. Too much of it could cause the room to overheat since there is likely to be excessive solar heat gains. In fact, if the shading device openings are inadequate, allowing too much natural light and solar radiation to enter the room, the HVAC system will have to work extra hard to reduce the temperature in the room, hence, the cooling loads will increase. This reflection makes optimisation of thermal and daylighting performance an interesting and important process in this research. A method to evaluate that the shading device is able to minimise the annual energy consumption whilst delivering a well daylit environment is needed.

There are two types of optimisation: single-objective and multi-objective. Multi-objective optimisation, which is the case in this study, concerns with two or more objective functions, for instance, minimising energy consumption and maximising daylight levels; which could be contradictory to each other. As a result, a multidimensional solution space is generated in the form of combined variables. In this study, daylight metrics – UDI and sDA, conflict with annual energy consumption – heating and cooling loads, plus lighting gains. Thus, the optimisation process analyses their combined effect in its quest for optimum solutions of façade apertures.

7.5.1 Annual Daylighting

Spatial daylight autonomy – sDA:

Before undertaking a solar sun cast analysis, one relevant term needs to be defined; a cloud cover. In building performance simulation, understanding the cloud distribution of the sky, which is deeply embedded within climate-adaptive weather data, can help to understand of complicated phenomena such as daylighting and solar radiation calculations (Darula and Kittler, 2002).

Within simulation tools, a cloud cover is specified through standard CIE sky; clear sky, partly cloudy sky, overcast sky. For example, a clear and partly cloudy sky are likely to generate high global levels of illuminance (light) and solar radiation (heat). In extreme cases, such as a heavily overcast sky, due to the dense cloud filter, diffuse light levels are likely to be deficient. Table 7.9 shows average monthly global horizontal illuminance (GHI) and direct normal illuminance (DNI) in three key cities relevant to this study; Hanoi, Hue and Saigon.

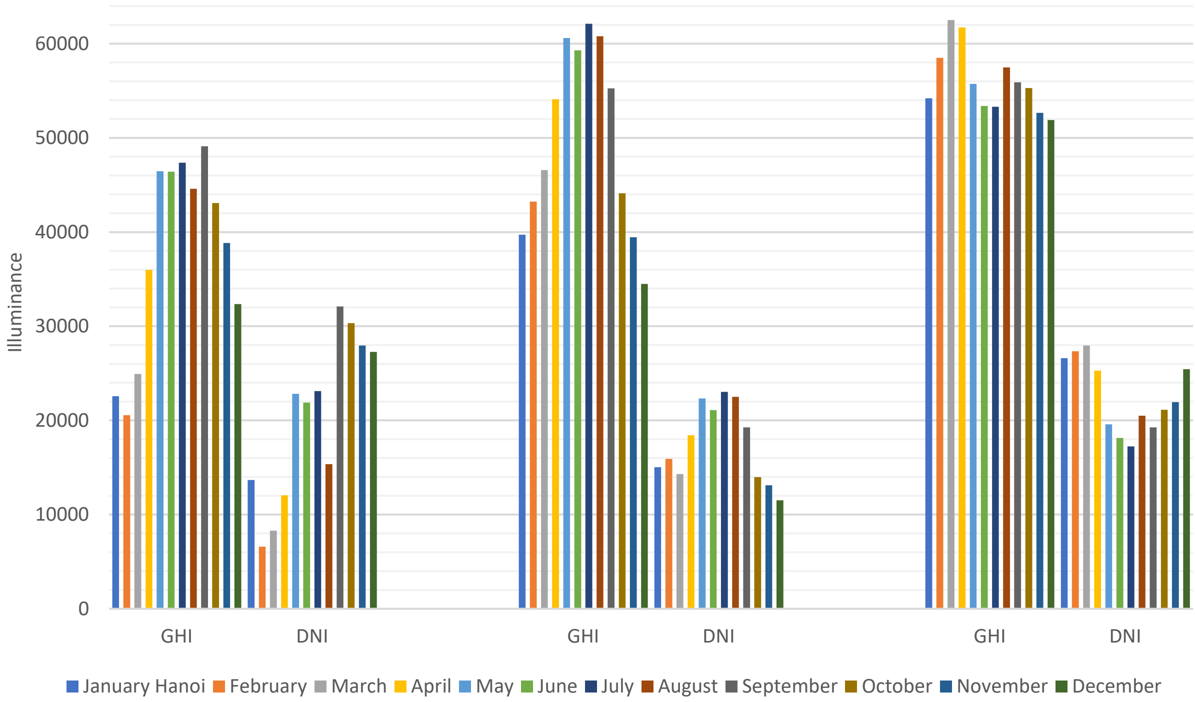

Figure 7.11 Average monthly global horizontal illuminance (GHI) and direct normal illuminance (DNI) in Hanoi, Hue and Saigon (from left to right).

Evidently, both GHI and DNI over the year in Hanoi are lower than that in Hue and Saigon. This is due to cloud cover in Hanoi having a higher density than that in the other two cities, for the most time of the year (see Figure 7.12). Understandably, cloud cover (CC) makes more impact on DNI than on GHI. Indeed, CC in the three cities shows an almost diverse pattern to DNI behaviour over the year, while GHI shows a less similar pattern.

Specifically, in terms of DNI, Saigon is highest with a total annual value of 270,415 lx, the number for Hanoi and Hue are 241,455 and 210,517 lx, respectively. In contrast, cloud cover in Saigon is lowest, with average monthly coverage of 62.9%; Hue has the highest value of 76.7%, and Hanoi has 75.8%. For GHI, Saigon is also the brightest city, receiving 672,603 lx annually; Hanoi gets the least: 452,216 lx and Hue in the middle with 599,758 lx.

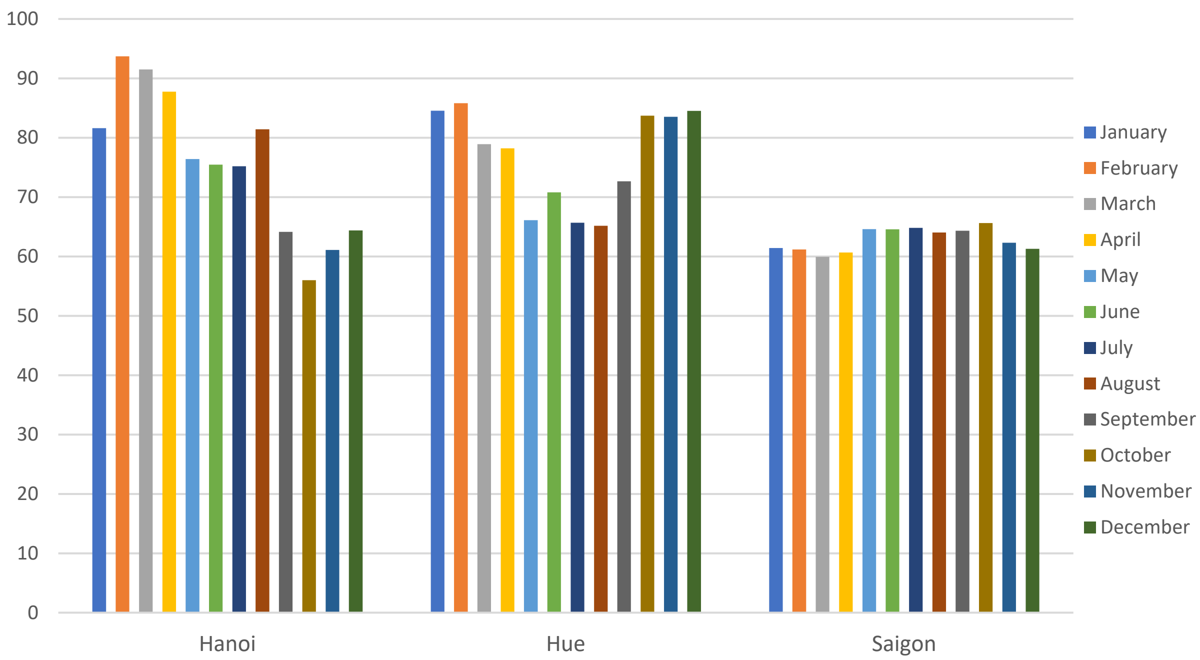

Figure 7.12 Cloud cover in the three cities.

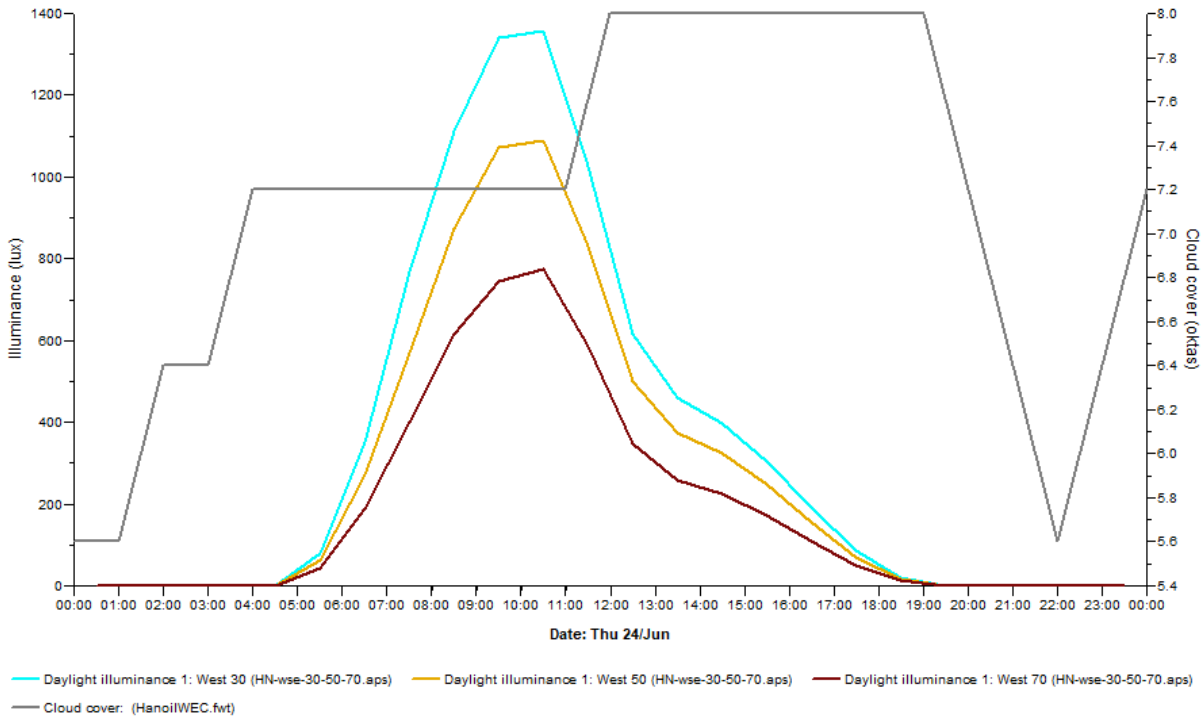

Figure 7.13 Relationship between daylight illuminance and cloud cover.

Figure 7.13 shows cloud cover increases gradually in the morning and remains continuously high in the afternoon, on a summer day. These changes dramatically affect natural daylight availability in the office as light levels increase when cloud cover is low and decrease when it is high.

IES Spatial Daylight Autonomy is one of LEED v4 approved methods in Lighting Measurements (LM) 83-12, which was standardised by Illuminating Engineering Society (2012). It requires designers to provide enough daylight in the space during working hours (8 am – 6 pm). It is the % of floor area that gets more than 300 lux for at least 50% of occupied hours. If 75% or more of the floor area achieves that, the solution is known as a "preferred daylight" solution. Given a specific approach to spatial layout partitioning in this case study, direct daylight comes into space from only one direction (i.e. west, south and east-facing office space); this means each space will vary in amount of DNI relative to the time of the day, whereas GHI will influence the metrics all day long. However, its impact is much weaker than DNI's, since it is diffuse light.

Figure 7.14 gives a general insight into the relationship between sDA and the apertures, for Hanoi. There is a small difference between the three distinct apertures - 30%, 50% and 70%, on three sides of the case.

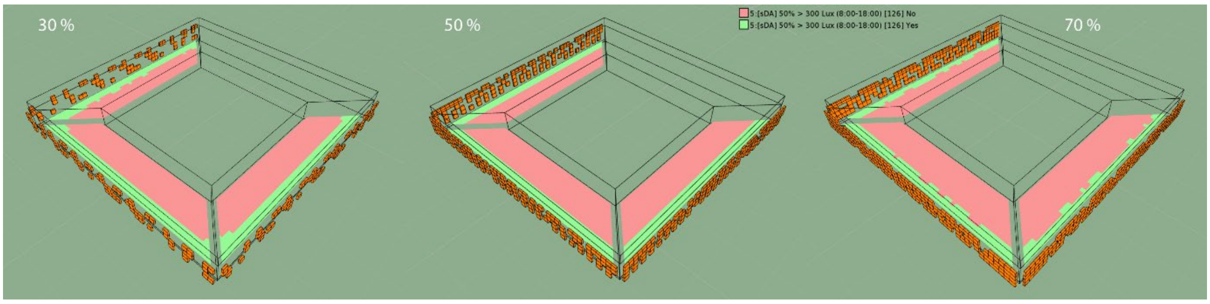

Figure 7.14 Annual $sDA_{50\%\text{-}300\ Lx}$ for Hanoi spaces with different shading percentages. (Source: Author).

Table 7.8 Statistical sDA results for 8 tested aperture opening scenarios on east, south and west, for the three cities

Space ID	**Hanoi**	**Hue**	**Saigon**
	$sDA_{300/50\%}$	$sDA_{300/50\%}$	$sDA_{300/50\%}$
West 0	38.18	**52.95**	**67.95**
West 20	34.55	40.23	49.09
West 30	27.50	36.82	43.18
West 40	23.86	28.64	36.14
West 50	23.64	23.64	29.55
West 60	21.36	23.64	24.32

West 70	20.23	22.50	23.86
West 80	14.55	16.14	22.95
East 0	46.74	**58.26**	**70.30**
East 20	43.70	48.40	**57.39**
East 30	35.65	44.35	**50.87**
East 40	34.78	39.78	46.96
East 50	31.25	34.78	36.74
East 60	31.52	31.44	35.22
East 70	26.96	30.65	33.48
East 80	25.65	26.90	32.61
South 0	35.23	46.14	**51.82**
South 20	27.73	40.68	43.41
South 30	24.55	37.00	40.82
South 40	23.64	36.77	37.50
South 50	34.57	34.57	35.22
South 60	22.95	33.64	34.64
South 70	32.39	30.35	32.57
South 80	13.18	28.90	30.41

Table 7.8 shows the $sDA_{300/50\%}$ statistics of the sides in the three cities. The strong connection between sDA and DNI explains a relatively low value of $sDA_{300/50\%}$ across the table as there is none that exceed 75%.

Generally, Saigon has the highest numbers on all three sides, and its east side office space (non-shaded) is the brightest of all scenarios. The west-facing office space in Hanoi, in contrast, gets the least $sDA_{300/50\%}$. This is due to average annual cloud cover in Hue and Saigon being similarly low (Figure 7.13), whilst average cloud cover in Hanoi is higher in the afternoon, reducing the amount of direct light for the western facing office space.

Also, the west-facing side has the most dramatic range of $sDA_{300/50\%;}$ differences are 23.63% in Hanoi, 36.81% in Hue and 45% in Saigon. These differences of changes in apertures on the south-facing facades are much lower and more stable: 22.05%, 17.24% and 21.41%, for each of the cities in the same order. The south-facing rooms receive the highest amount of diffuse light whilst direct light does not penetrate the rooms as deep as it does in the west and east-facing rooms, due to the high sun altitude angles (see Appendix D). It is worth noticing that the scope of this study does not extend to the impacts on and shading of roof skylights and glazed areas, where the situation is very different and more critical, due to high exposure to DNI from the sun at high altitude angles). Moreover, changes in solar azimuths on the West explain the dramatic differences of $sDA_{300/50\%}$, across all the apertures. The west side offices are exposed for longer hours in the afternoon compared to the east side offices in the morning.

In summary, offices in Hanoi get the least $sDA_{300/50\%}$ (30% average) on all sides. Saigon undoubtedly provides the highest $sDA_{300/50\%}$ (40.3%), with 35.3% for Hue. In the context of orientation, the east side receives highest $sDA_{300/50\%}$ (39% average). Westside facing rooms need to compensate the most as their total $sDA_{300/50\%}$ (31.3%) is the lowest. Southside facing offices are stable with total $sDA_{300/50\%}$ of 35.2%.

Shading wise, the base case scenario (no shading device) clearly provides the highest levels of sDA. Aperture wise, the pattern of daylight provision gives an expected linear trend, with 20% giving the most daylight provision and 80% the least.

Useful daylight illuminance – UDI:

UDI is a less 'strict' performance indicator than sDA, as it has only one variable, the floor area, instead of both floor area and occupied hours for sDA. LEED v4 requires at least 75% of the floor area having daylight level between 300 lx and 3000 lx – hence the term $UDI_{300\text{-}3000lx}$. The 'useful range' 300-3000 lx is considerably long, covering sufficient (300-500 lx), preferred (500-2500 lx) and exceeded levels (above 2500 lx); thus, $UDI_{300\text{-}3000lx}$ is substantially easier to achieve. Indeed, Table 7.9 shows a lot higher percentages compared to that of $sDA_{300/50\%}$.

Table 7.9. UDI results for 8 tested scenarios in three sides for the three cities.

Space ID	Hanoi	Hue	Saigon
	$UDI_{300\text{-}3000\ Lx}$	$UDI_{300\text{-}3000\ Lx}$	$UDI_{300\text{-}3000\ Lx}$
West 0	**100.00**	**100.00**	**100.00**
West 20	**95.50**	**100.00**	**100.00**
West 30	70.20	**100.00**	**100.00**
West 40	58.20	**97.00**	**100.00**
West 50	49.50	68.90	**99.50**
West 60	37.50	50.50	63.20
West 70	36.80	42.80	57.50
West 80	28.20	34.80	44.50
East 0	**100.00**	**99.30**	**98.70**
East 20	**87.40**	**100.00**	**100.00**
East 30	**73.30**	**100.00**	**100.00**
East 40	66.10	**82.80**	**100.00**
East 50	56.10	67.80	**89.60**
East 60	46.50	57.40	68.50
East 70	44.30	50.90	58.50

East 80	36.50	45.70	50.00
South 0	**100.00**	**100.00**	**100.00**
South 20	68.20	**100.00**	**100.00**
South 30	60.70	**100.00**	**100.00**
South 40	49.30	70.50	**99.30**
South 50	55.00	66.50	**78.30**
South 60	35.70	46.60	57.30
South 70	44.80	54.10	59.80
South 80	24.50	34.80	43.40

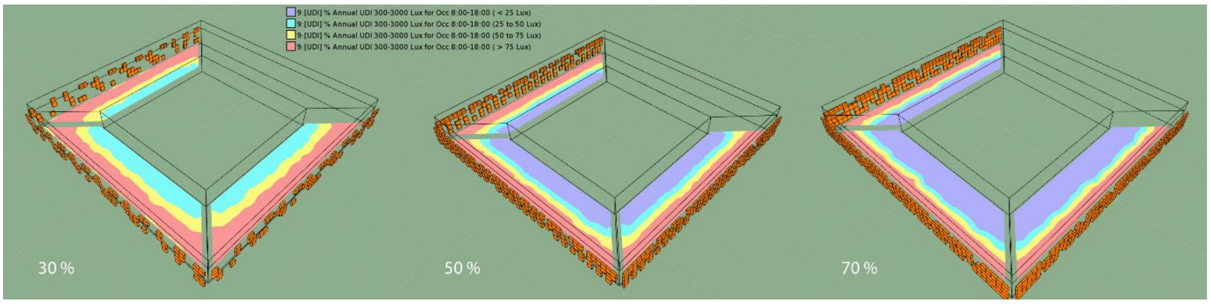

Figure 7.15 Annual UDI$_{300\text{-}3000\ Lx}$ for Hanoi office with different shading percentages (Source: Author).

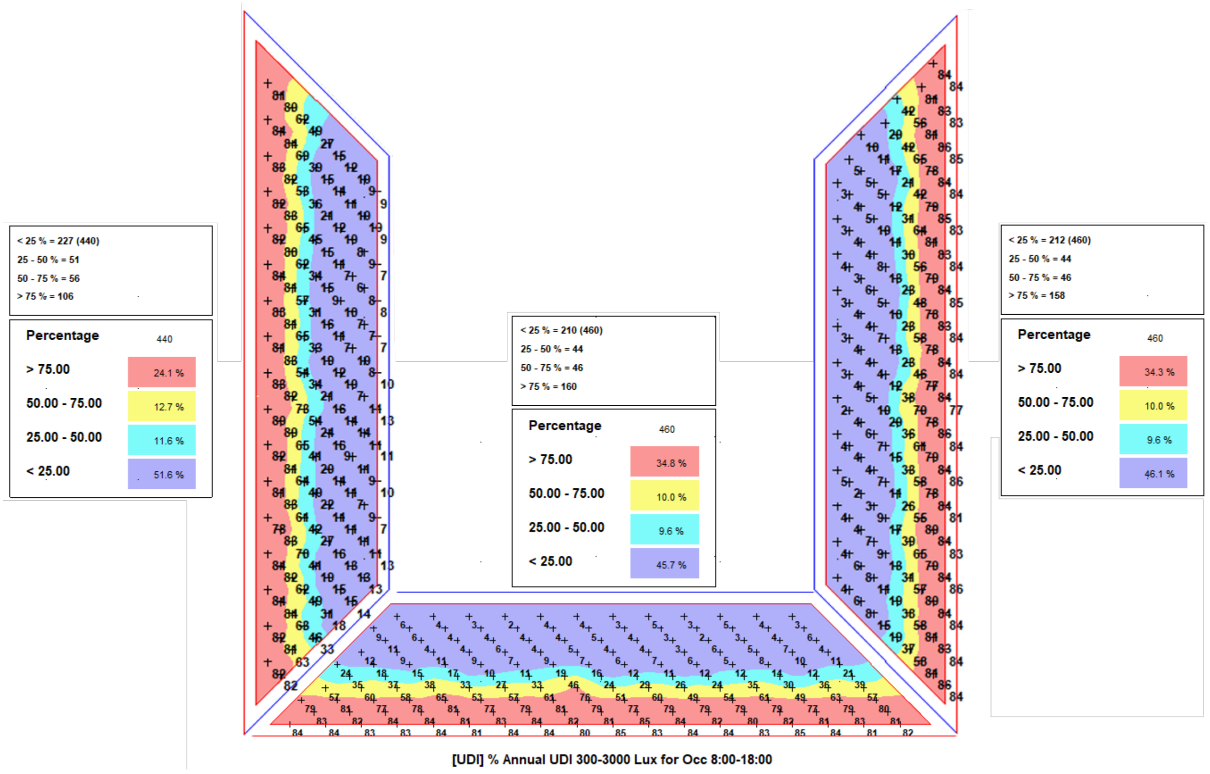

Figure 7.16 Annual UDI$_{300\text{-}3000\ Lx}$ for occupancy time 8:00 – 18:00 for Hanoi - 70% shaded. (Source: Author).

A similar pattern to $sDA_{300/50\%}$ can be seen, though the differences are less. The west-facing side in Hanoi has the lowest $sDA_{300/50\%}$, with an annual average percentage of 59%. Office in Saigon on the south-facing side receives the highest level, an annual average of 82%. The formal capital Hue on the east-facing side, is in the middle, with a 74% average.

7.5.2 Energy Consumption

Unlike natural light metrics, which are influenced by cloud cover (CC), global horizontal illuminance (GHI) and direct normal illuminance (DNI), energy demands are heavily driven by the outdoor temperature and solar radiation (see Figure 7.17 and Figure 7.18).

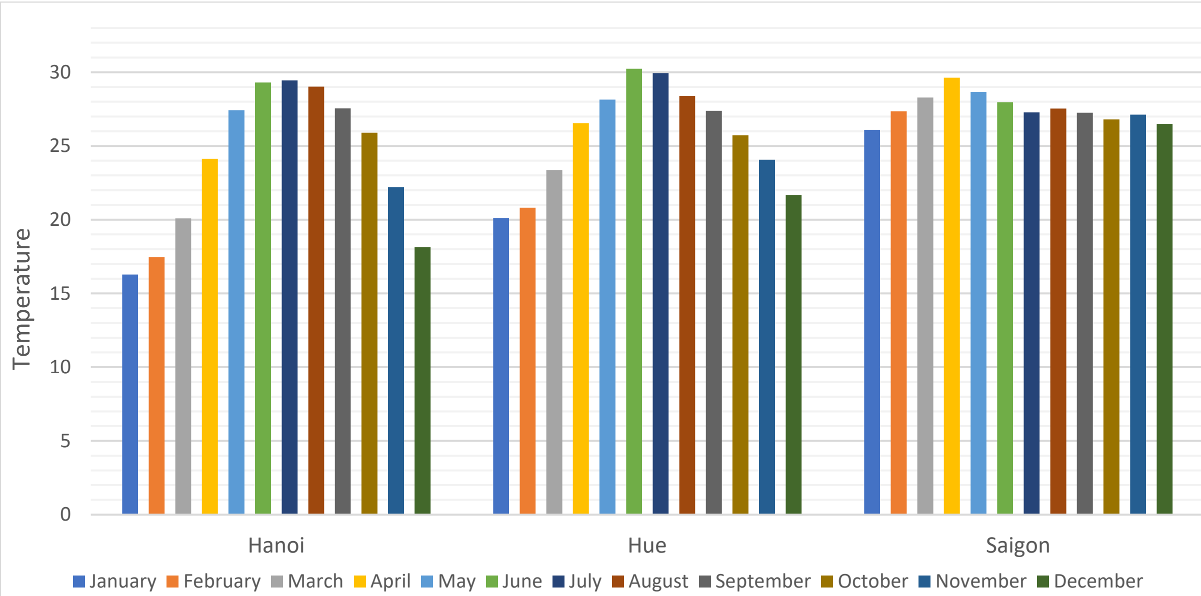

Figure 7.17 Average monthly temperature in the three cities. (Source: Author).

Average annual temperature in Hanoi, Hue and Saigon are 21 ºC, 24 ºC and 27 ºC, respectively. Hanoi in the North has four seasons, including a cold, short winter. The temperature in Saigon is more stable, changing a maximum 4ºC over the year. Hue's temperature is similar to Hanoi's, though 3ºC higher, on average. Geographic's locations also have an influence. Since Saigon is situated nearer to the equator than Hue and Hanoi are, it receives higher levels of solar radiation, both global horizontal and direct normal, than the others two cities do (see Figure 7.18).

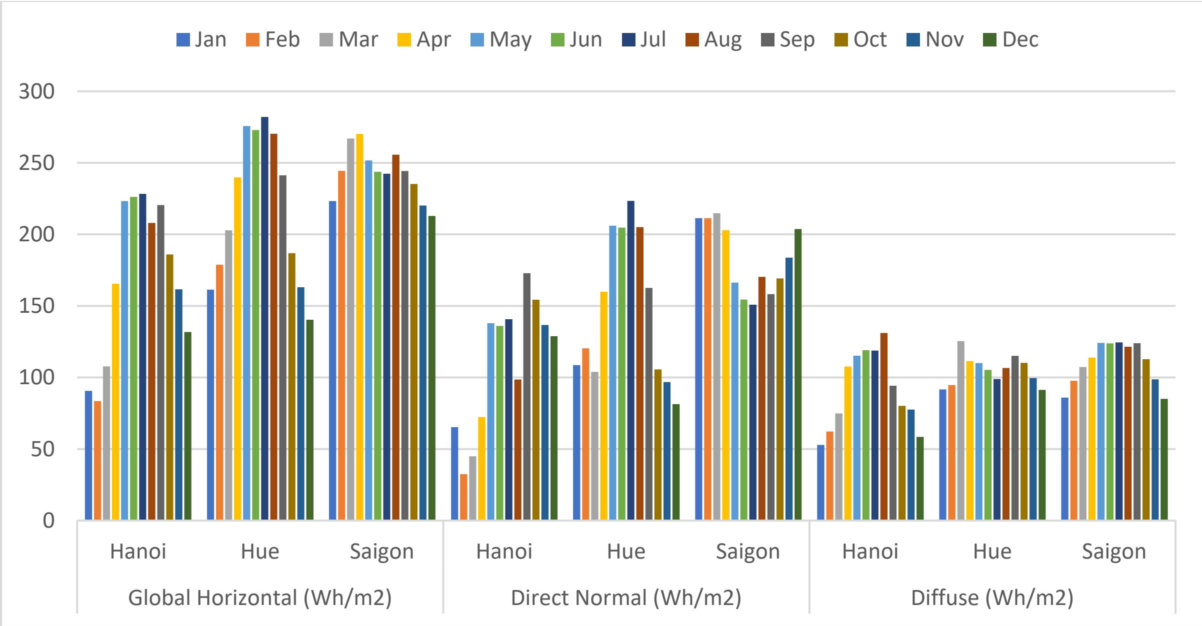

Figure 7.18. Average monthly global, direct and diffuse solar radiation in the three cities. (Source: Author).

The winter in Hanoi requires heating, though not significantly, in the first four months and the last month of the year. Hue needs heating only during the first two months, with small energy demands. There are no heating requirements in Saigon, for the whole of the year.

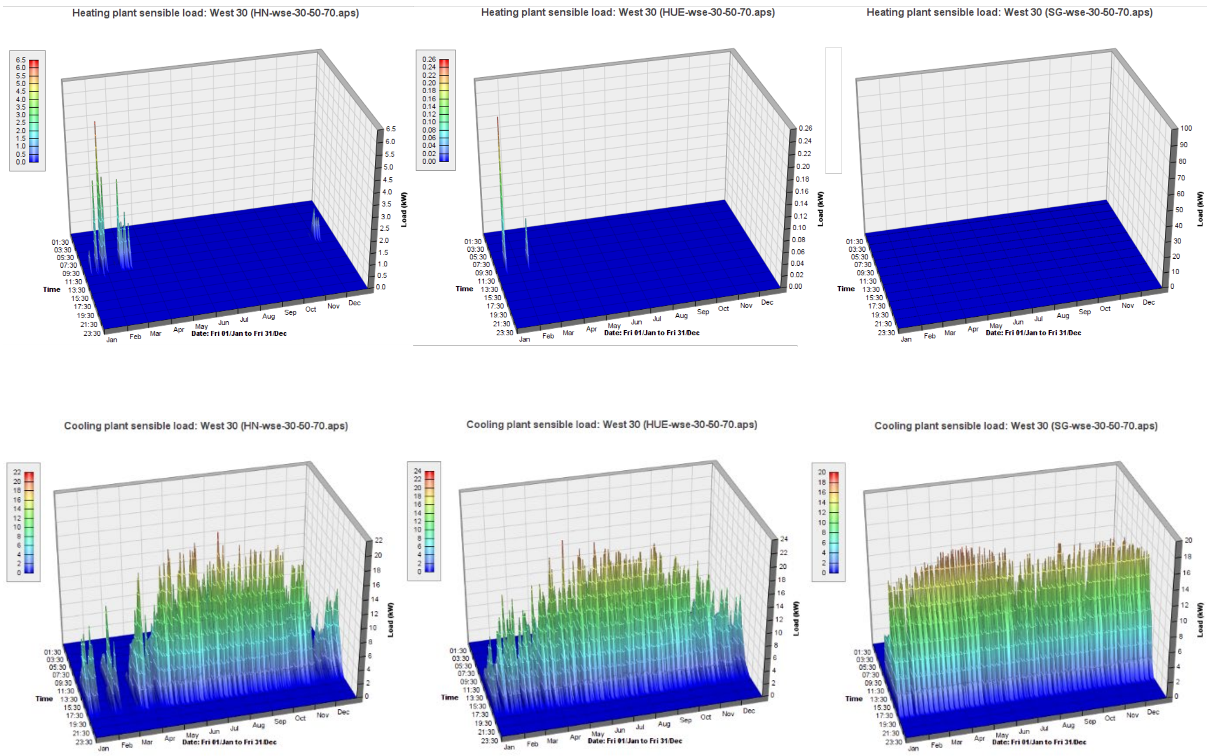

Figure 7.19 Annual heating (top) and cooling loads (down) in Hanoi, Hue and Saigon (from left to right). (Source: Author).

On the contrary, cooling loads show significant demands. Saigon demands high capacity of cooling, all year round, due to its high-level solar radiation and temperature. Hanoi and Hue have similar energy demands, requiring cooling after March (Figure 7.20).

Monthly energy demands (heating, cooling loads, internal and lighting gains), show a different pattern to that of daylight (see Table 7.10, Table 7.11 and Table 7.12). To aid its data visualisation, a 'traffic light' colour coding system is introduced, with red cells representing high energy consumption and green cells lower energy consumption.

Table 7.13. West facing office scenario - Monthly energy loads for the three cities (KWh/m^2).

		West	West 20	West 30	West 40	West 50	West 60	West 70	West 80	West Kinetic
Hanoi	Jan	302.14	292.30	289.71	279.39	274.15	280.32	290.17	296.03	240.32
	Feb	195.08	184.58	180.92	173.68	168.95	167.16	169.32	167.76	149.01
	Mar	503.55	471.65	457.11	438.50	422.78	411.09	410.84	401.35	384.05
	Apr	870.40	820.77	796.46	769.10	744.17	721.16	724.48	706.81	697.63
	May	1265.90	1202.72	1167.04	1127.55	1095.78	1058.52	1063.13	1034.34	1033.02
	Jun	1502.43	1434.64	1400.42	1356.01	1324.03	1289.97	1288.88	1260.18	1258.65
	Jul	1541.36	1475.05	1440.38	1396.85	1365.26	1330.89	1329.89	1302.62	1300.40
	Aug	1357.61	1301.97	1274.68	1240.99	1213.23	1184.98	1191.23	1171.21	1162.92
	Sep	1346.67	1278.83	1243.47	1206.83	1166.57	1135.33	1138.58	1115.98	1106.45
	Oct	1080.07	1015.31	985.78	945.35	913.34	886.04	883.61	864.24	861.05
	Nov	826.77	774.71	752.45	714.64	688.13	673.17	682.49	676.05	644.62
	Dec	463.96	422.58	407.53	381.61	362.35	361.18	372.77	374.22	328.00

		West	West 20	West 30	West 40	West 50	West 60	West 70	West 80	West Kinetic
Hue	Jan	550.23	504.83	488.83	456.39	436.04	426.75	429.27	428.85	409.25
	Feb	725.63	660.82	633.44	592.52	561.94	535.69	532.94	515.33	510.71
	Mar	1059.56	993.55	961.34	924.00	887.06	857.25	856.90	833.11	828.72
	Apr	1358.25	1289.31	1251.78	1210.84	1175.34	1138.57	1137.77	1111.97	1108.94
	May	1492.37	1423.06	1383.49	1338.73	1303.11	1264.34	1264.00	1233.09	1232.75
	Jun	1858.98	1777.22	1732.90	1681.67	1640.07	1595.09	1599.28	1561.18	1561.15
	Jul	1818.54	1738.41	1694.86	1642.44	1599.47	1554.10	1559.24	1520.94	1520.65
	Aug	1576.98	1502.87	1459.60	1415.31	1379.04	1336.27	1340.42	1309.85	1305.10
	Sep	1576.32	1491.18	1445.27	1402.43	1352.16	1308.33	1308.31	1274.28	1272.42
	Oct	1134.19	1065.45	1031.70	987.17	951.72	921.70	917.23	893.27	891.88
	Nov	959.25	904.03	883.66	844.11	819.75	805.55	809.37	804.19	783.58
	Dec	668.80	625.27	609.42	578.62	560.08	553.12	558.12	559.42	529.48

		West	West 20	West 30	West 40	West 50	West 60	West 70	West 80	West Kinetic
Saigon	Jan	1140.88	1075.78	1051.10	1009.49	977.40	952.76	957.79	948.98	940.87
	Feb	1368.89	1297.13	1264.71	1217.55	1179.46	1146.43	1140.23	1111.91	1111.89
	Mar	1732.21	1646.08	1600.84	1558.46	1509.47	1464.94	1466.72	1432.95	1430.13
	Apr	1670.75	1601.26	1561.25	1519.21	1486.22	1445.77	1443.92	1415.65	1414.03

	May	1416.92	1354.51	1320.57	1278.53	1249.47	1216.87	1215.72	1187.71	1187.41
	Jun	1511.68	1437.72	1400.59	1355.78	1316.34	1279.19	1281.66	1249.12	1248.90
	Jul	1427.18	1355.58	1319.31	1274.95	1239.81	1203.82	1203.93	1173.74	1173.16
	Aug	1397.96	1331.34	1293.36	1250.70	1217.01	1177.14	1184.06	1153.72	1149.64
	Sep	1509.22	1431.08	1389.02	1346.60	1305.03	1263.02	1264.28	1230.62	1227.40
	Oct	1342.78	1267.37	1228.22	1186.01	1143.67	1109.05	1102.41	1073.92	1073.76
	Nov	1494.78	1414.12	1377.25	1325.91	1287.15	1257.93	1264.06	1244.32	1234.52
	Dec	1435.07	1355.35	1326.64	1273.33	1238.03	1207.99	1214.18	1202.97	1191.36

Table 7.11 East facing office scenario - Monthly energy loads for the three cities (KWh/m^2).

		East	East 20	East 30	East 40	East 50	East 60	East 70	East 80	East Kinetic
Hanoi	Jan	264.90	259.58	260.73	255.29	257.27	265.88	277.94	283.91	217.44
	Feb	194.04	183.50	179.29	172.78	167.46	166.92	167.75	167.49	147.75
	Mar	439.74	419.09	409.91	399.48	388.21	385.55	387.06	384.89	362.06
	Apr	773.63	740.69	724.36	708.51	688.32	682.40	682.02	679.31	662.36
	May	1244.39	1184.79	1147.56	1116.81	1076.81	1055.30	1042.83	1030.86	1025.85
	Jun	1468.12	1406.90	1370.64	1337.73	1297.51	1277.38	1263.88	1252.09	1247.35
	Jul	1561.86	1493.34	1451.16	1414.52	1368.29	1343.90	1330.84	1315.63	1310.80
	Aug	1378.94	1321.55	1288.88	1260.34	1221.84	1204.24	1197.83	1188.13	1175.03
	Sep	1337.90	1275.46	1236.42	1211.70	1164.24	1147.46	1141.06	1131.30	1117.47
	Oct	1027.55	976.73	950.00	922.88	890.64	878.59	870.68	867.81	855.97
	Nov	741.26	703.55	688.94	666.58	644.53	643.46	647.47	659.08	599.31
	Dec	367.52	343.32	333.85	325.30	315.57	327.93	338.49	357.86	280.11

		East	East 20	East 30	East 40	East 50	East 60	East 70	East 80	East Kinetic
Hue	Jan	468.83	438.73	424.07	409.63	390.36	392.65	400.57	407.38	370.02
	Feb	607.72	566.62	544.93	524.65	499.43	490.94	490.95	486.09	475.94
	Mar	1040.08	977.78	941.81	913.13	871.26	855.14	845.62	836.74	827.53
	Apr	1321.75	1260.91	1223.16	1192.15	1150.06	1128.89	1120.67	1112.75	1098.84
	May	1429.88	1371.32	1331.97	1302.32	1260.11	1240.64	1225.39	1217.19	1211.17
	Jun	1782.72	1715.79	1673.23	1639.68	1592.47	1572.08	1555.92	1547.08	1540.93
	Jul	1793.82	1717.81	1669.67	1629.66	1576.30	1550.08	1533.60	1520.05	1514.85
	Aug	1516.04	1453.68	1412.17	1381.15	1338.94	1315.94	1305.47	1296.91	1281.91
	Sep	1471.75	1410.44	1372.47	1343.25	1301.44	1283.63	1273.49	1264.42	1254.75
	Oct	1024.05	977.67	951.95	927.23	897.85	886.75	879.73	873.40	867.95
	Nov	891.37	850.52	830.88	809.10	784.48	778.81	786.51	792.18	750.89
	Dec	634.68	598.93	582.29	563.61	541.56	544.19	555.42	560.39	512.26

		East	East 20	East 30	East 40	East 50	East 60	East 70	East 80	East Kinetic
Saigon	Jan	1163.05	1094.16	1058.54	1026.15	980.92	965.00	966.18	958.96	927.26
	Feb	1391.37	1315.69	1272.32	1231.52	1178.74	1153.38	1141.09	1127.97	1117.78
	Mar	1720.72	1639.95	1590.55	1555.86	1498.14	1471.93	1458.57	1447.58	1430.30
	Apr	1691.84	1619.34	1572.19	1535.96	1485.47	1455.72	1446.09	1431.93	1416.35
	May	1456.66	1385.58	1342.14	1298.30	1255.98	1230.83	1214.94	1199.74	1196.18
	Jun	1526.87	1451.03	1405.01	1365.90	1313.84	1290.07	1272.91	1257.37	1253.60
	Jul	1436.17	1364.12	1320.35	1283.09	1234.87	1212.06	1195.37	1180.90	1176.49
	Aug	1398.67	1333.01	1290.09	1255.80	1209.29	1182.85	1176.68	1164.01	1150.16

Sep	1489.44	1417.73	1374.02	1340.01	1290.33	1266.88	1254.13	1239.69	1230.03
Oct	1343.29	1272.03	1228.17	1192.36	1141.72	1123.00	1107.07	1095.60	1089.04
Nov	1488.83	1413.14	1372.82	1335.89	1285.17	1267.66	1265.82	1254.76	1223.15
Dec	1414.37	1341.12	1304.27	1271.70	1222.65	1212.93	1216.37	1203.23	1165.72

Table 7.12 South facing office scenario - Monthly energy loads for the three cities (KWh/m^2).

		South	South 20	South 30	South 40	South 50	South 60	South 70	South 80	South Kinetic
Hanoi	Jan	443.94	407.33	387.90	356.39	343.28	329.82	336.14	328.55	280.17
	Feb	289.37	262.13	248.17	224.66	212.90	204.73	204.90	197.55	179.45
	Mar	518.41	486.22	471.85	440.51	429.18	424.19	426.86	421.44	400.91
	Apr	751.15	729.37	724.78	700.00	691.62	690.77	692.54	688.85	672.89
	May	1032.49	1009.44	1004.07	984.87	971.93	965.83	965.89	961.86	956.27
	Jun	1281.05	1252.17	1245.79	1221.60	1204.97	1196.93	1196.17	1188.57	1183.47
	Jul	1321.95	1293.67	1287.33	1263.83	1247.76	1239.76	1239.03	1232.89	1226.75
	Aug	1253.20	1223.95	1218.22	1192.21	1176.42	1170.21	1170.90	1166.76	1153.01
	Sep	1365.52	1310.96	1280.64	1213.73	1197.48	1183.44	1193.61	1179.14	1169.46
	Oct	1395.99	1275.71	1214.97	1108.75	1059.80	1018.62	1015.37	980.96	976.99
	Nov	1177.15	1064.00	1003.50	902.78	859.56	815.24	808.93	770.52	738.65
	Dec	682.44	612.16	566.70	510.84	480.57	455.10	455.70	439.06	397.59

		South	South 20	South 30	South 40	South 50	South 60	South 70	South 80	South Kinetic
Hue	Jan	832.41	737.36	689.69	608.03	569.78	535.13	535.20	501.92	487.19
	Feb	1018.91	901.49	844.78	741.09	692.86	653.15	651.96	622.36	614.99
	Mar	1104.28	1038.91	1009.98	939.40	916.45	898.36	903.27	888.05	881.09
	Apr	1147.84	1125.51	1121.06	1101.10	1089.17	1085.32	1088.48	1085.13	1071.59
	May	1176.20	1157.38	1152.30	1136.56	1126.09	1120.13	1119.30	1114.45	1110.04
	Jun	1500.76	1480.75	1475.38	1458.57	1446.71	1439.99	1439.42	1435.22	1430.49
	Jul	1449.23	1431.01	1426.06	1410.67	1399.80	1393.69	1393.71	1389.63	1384.86
	Aug	1276.12	1256.81	1252.52	1236.29	1227.14	1223.40	1225.52	1226.16	1208.98
	Sep	1504.03	1465.93	1440.36	1369.51	1366.27	1361.68	1364.61	1353.80	1344.64
	Oct	1309.66	1212.49	1164.00	1073.94	1033.75	1002.38	1002.50	975.02	973.84
	Nov	1272.37	1162.83	1111.63	1019.06	971.54	933.13	934.20	904.65	877.34
	Dec	975.42	879.61	833.47	748.84	709.85	676.90	677.18	651.64	623.39

		South	South 20	South 30	South 40	South 50	South 60	South 70	South 80	South Kinetic
Saigon	Jan	1708.09	1544.60	1455.47	1312.81	1243.18	1186.38	1176.96	1126.64	1119.88
	Feb	1725.27	1592.05	1517.51	1389.47	1337.46	1296.99	1297.05	1258.42	1258.39
	Mar	1660.92	1619.77	1591.32	1517.98	1515.79	1514.09	1521.01	1509.32	1496.62
	Apr	1391.06	1370.18	1364.50	1347.47	1336.22	1331.55	1331.18	1333.26	1319.58
	May	1190.20	1165.91	1159.55	1138.16	1122.85	1115.27	1112.59	1106.28	1103.21
	Jun	1264.86	1235.46	1228.42	1202.85	1184.43	1175.04	1173.20	1166.01	1161.94
	Jul	1200.21	1169.62	1162.59	1135.64	1116.97	1107.18	1105.11	1097.70	1093.15
	Aug	1140.86	1117.15	1111.31	1091.31	1077.87	1072.57	1071.03	1066.70	1055.61
	Sep	1341.15	1311.77	1304.71	1270.91	1262.63	1254.80	1253.68	1248.80	1239.73
	Oct	1513.20	1417.86	1365.96	1263.35	1232.76	1207.84	1214.31	1187.36	1184.84
	Nov	2013.08	1840.27	1748.86	1601.42	1536.42	1475.19	1472.36	1421.05	1409.75
	Dec	2095.46	1903.31	1800.58	1632.84	1551.29	1481.69	1471.98	1410.37	1401.61

Three tables show similar patterns: green colours are seen more in Hanoi and Hue than in Saigon, especially in the first and the last two months of the year. Saigon's data show colours mostly in warm range. Energy consumption of the west-facing side scenario is almost identical to the east-facing side, with energy loads for south-facing office scenario being the highest of all orientations. Peak temperatures and high direct normal radiation in the dry season (November – April) lead to highest cooling demands in Saigon, across all aperture scenarios. Saigon load demands are lesser than Hui and Hanoi in summer months (June – July). It is important to note that the kinetic scenario has the lowest energy loads, in all three cities and for all orientations.

Table 7.13 All three office facing scenarios – Annual energy loads for the three cities (KWh/m^2).

		Hanoi	Hue	Saigon
Reference (0%)	West	11255.95	14779.11	17448.32
	East	10799.85	13982.69	17521.27
	South	11512.67	14567.22	18244.36
20%	West	10675.11	13976.00	16567.33
	East	10308.49	13340.21	16646.90
	South	10927.10	13850.08	17287.96
30%	West	10395.94	13576.28	16132.87
	East	10041.74	12958.61	16130.49
	South	10653.93	13521.23	16810.80
40%	West	10030.52	13074.21	15596.53
	East	9791.90	12635.56	15692.54
	South	10120.18	12843.07	15904.21
50%	West	9738.73	12665.78	15149.06
	East	9480.69	12204.26	15097.12
	South	9875.46	12549.42	15517.88
60%	West	9499.81	12296.77	14724.90
	East	9379.01	12039.74	14832.31
	South	9694.64	12323.26	15218.60
70%	West	9545.39	12312.83	14738.96
	East	9347.86	11973.33	14715.22
	South	9706.04	12335.35	15200.44
80%	West	9370.79	12045.48	14425.63
	East	9318.36	11914.60	14561.74
	South	9556.15	12148.02	14931.90
Kinetic	West	**9166.12**	11954.61	14383.07
	East	9001.49	11707.05	14376.05
	South	9335.60	12008.44	14844.31

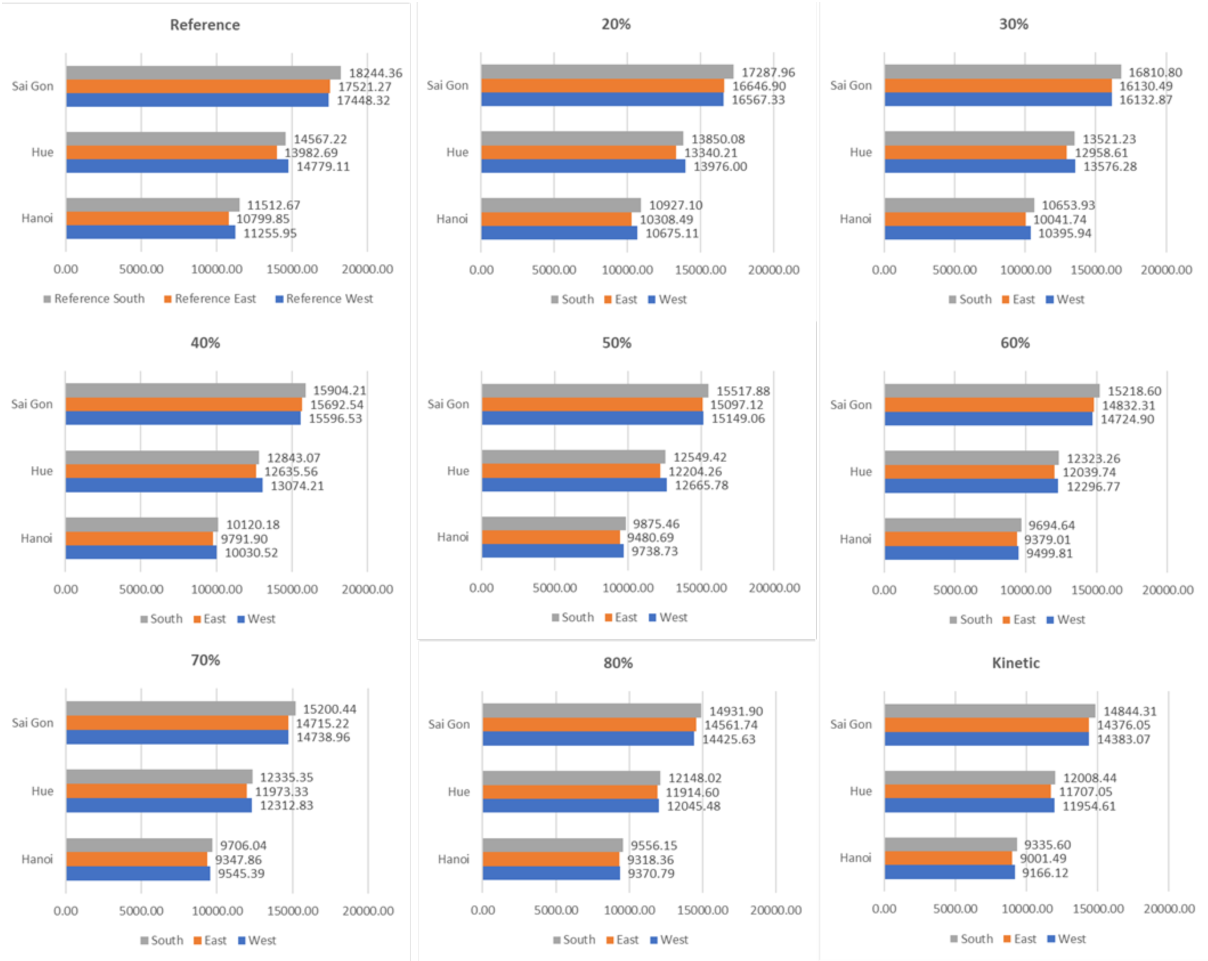

Figure 7.18 Annual energy consumption of the three cities with eight apertures and reference case (KWh/m^2) (Source: Author)

Total annual energy loads are shown in Table 7.13 and Fig 7.18. Saigon scenarios demand the most energy on all sides while Hanoi demands the least. Interestingly, unlike daylighting metrics, energy demands on the East facing side are the lowest across all cities, while the south-facing rooms require the highest energy loads. East facing side office gets more light in the morning but also benefit from cooler air in the morning, as temperature as well as sunlight intensity both tend to increase in the afternoon.

Energy demands gradually decrease following the increase in apertures of shading devices. The reference case (no solar shading) has highest energy load demands peaking at 18,244 KWh/m^2 on the south side facing office in Saigon. The fixed shading scenarios save more energy than 'no solar shading' reference case, starting from the aperture of 20%. 80% is the best-fixed shading scenario as far as energy demands alone are concerned, with the lowest energy consumption all around. Its peak performance is seen on the east-facing side in Hanoi with the energy demand of 9,318 KWh/m^2.

However, the 'kinetic' scenario saves the most, with the lowest energy demands for all cities and for all orientations. Its lowest value is 9,001 KWh/m^2 (Hanoi – east side), which is 1798 KWh/m^2 (20%) less than 'no-shading' reference case and 317 KWh/m^2 (3.5%) lower than the 'best-fixed' case of 80% aperture. At its high peak, the kinetic scenario has 14,844 KWh/m^2 (Saigon - south side), which is 3400 KWh/m^2 (23%) lower than that of the 'no-shading' reference case and 88 KWh/m^2 (0.6%) lower than the 'best-fixed' case of 80% aperture. It is also important to note that energy savings expressed in percentages have to be understood within its context, as a similar percentage of both high (23%) and low peak (20%) comparison to 'no shading' reference case, has 1602 KWh/m^2 difference in absolute value.

For a commercial building with a large floor area, using shading strategies would lead to substantial annual savings. The percentage reduction rate is presented in Tables 7.19, 7.20 and 7.21.

7.5.3 Energy Reduction Rate

Table 7.14 The reduction rate of energy on the Westside for the three cities (%).

		West	West 20	West 30	West 40	West 50	West 60	West 70	West 80	West Kinetic
Hanoi	Jan	0%	3.26%	4.11%	7.53%	9.27%	7.22%	3.96%	2.02%	20.46%
	Feb	0%	5.38%	7.26%	10.97%	13.40%	14.31%	13.21%	14.01%	23.62%
	Mar	0%	6.33%	9.22%	12.92%	16.04%	18.36%	18.41%	20.30%	23.73%
	Apr	0%	5.70%	8.49%	11.64%	14.50%	17.15%	16.77%	18.79%	19.85%
	May	0%	4.99%	7.81%	10.93%	13.44%	16.38%	16.02%	18.29%	18.40%
	Jun	0%	4.51%	6.79%	9.75%	11.87%	14.14%	14.21%	16.12%	16.23%
	Jul	0%	4.30%	6.55%	9.38%	11.42%	13.65%	13.72%	15.49%	15.63%
	Aug	0%	4.10%	6.11%	8.59%	10.64%	12.72%	12.26%	13.73%	14.34%
	Sep	0%	5.04%	7.66%	10.38%	13.37%	15.69%	15.45%	17.13%	17.84%
	Oct	0%	6.00%	8.73%	12.47%	15.44%	17.96%	18.19%	19.98%	20.28%
	Nov	0%	6.30%	8.99%	13.56%	16.77%	18.58%	17.45%	18.23%	22.03%
	Dec	0%	8.92%	12.16%	17.75%	21.90%	22.15%	19.65%	19.34%	29.30%
		West	**West 20**	**West 30**	**West 40**	**West 50**	**West 60**	**West 70**	**West 80**	**West Kinetic**

Hue	Jan	0%	8.25%	11.16%	17.05%	20.75%	22.44%	21.98%	22.06%	25.62%
	Feb	0%	8.93%	12.70%	18.34%	22.56%	26.18%	26.55%	28.98%	29.62%
	Mar	0%	6.23%	9.27%	12.79%	16.28%	19.09%	19.13%	21.37%	21.79%
	Apr	0%	5.08%	7.84%	10.85%	13.47%	16.17%	16.23%	18.13%	18.36%
	May	0%	4.64%	7.30%	10.30%	12.68%	15.28%	15.30%	17.37%	17.40%
	Jun	0%	4.40%	6.78%	9.54%	11.78%	14.20%	13.97%	16.02%	16.02%
	Jul	0%	4.41%	6.80%	9.68%	12.05%	14.54%	14.26%	16.36%	16.38%
	Aug	0%	4.70%	7.44%	10.25%	12.55%	15.26%	15.00%	16.94%	17.24%
	Sep	0%	5.40%	8.31%	11.03%	14.22%	17.00%	17.00%	19.16%	19.28%
	Oct	0%	6.06%	9.04%	12.96%	16.09%	18.74%	19.13%	21.24%	21.36%
	Nov	0%	5.76%	7.88%	12.00%	14.54%	16.02%	15.62%	16.17%	18.31%
	Dec	0%	6.51%	8.88%	13.48%	16.26%	17.30%	16.55%	16.35%	20.83%
Saigon		**West**	**West 20**	**West 30**	**West 40**	**West 50**	**West 60**	**West 70**	**West 80**	**West Kinetic**
	Jan	0%	5.71%	7.87%	11.52%	14.33%	16.49%	16.05%	16.82%	17.53%
	Feb	0%	5.24%	7.61%	11.06%	13.84%	16.25%	16.70%	18.77%	18.77%
	Mar	0%	4.97%	7.58%	10.03%	12.86%	15.43%	15.33%	17.28%	17.44%
	Apr	0%	4.16%	6.55%	9.07%	11.04%	13.47%	13.58%	15.27%	15.37%
	May	0%	4.40%	6.80%	9.77%	11.82%	14.12%	14.20%	16.18%	16.20%
	Jun	0%	4.89%	7.35%	10.31%	12.92%	15.38%	15.22%	17.37%	17.38%
	Jul	0%	5.02%	7.56%	10.67%	13.13%	15.65%	15.64%	17.76%	17.80%
	Aug	0%	4.77%	7.48%	10.53%	12.94%	15.80%	15.30%	17.47%	17.76%
	Sep	0%	5.18%	7.96%	10.78%	13.53%	16.31%	16.23%	18.46%	18.67%
	Oct	0%	5.62%	8.53%	11.68%	14.83%	17.41%	17.90%	20.02%	20.03%
	Nov	0%	5.40%	7.86%	11.30%	13.89%	15.85%	15.44%	16.76%	17.41%
	Dec	0%	5.55%	7.56%	11.27%	13.73%	15.82%	15.39%	16.17%	16.98%

Table 7.15 The reduction rate of energy on the Eastside for the three cities (%).

		East	East 20	East 30	East 40	East 50	East 60	East 70	East 80	East Kinetic
Hanoi	Jan	0%	2.01%	1.57%	3.63%	2.88%	-0.37%	-4.93%	-7.18%	17.91%
	Feb	0%	5.44%	7.60%	10.96%	13.70%	13.98%	13.55%	13.68%	23.86%
	Mar	0%	4.70%	6.78%	9.16%	11.72%	12.32%	11.98%	12.47%	17.66%
	Apr	0%	4.26%	6.37%	8.42%	11.03%	11.79%	11.84%	12.19%	14.38%
	May	0%	4.79%	7.78%	10.25%	13.47%	15.20%	16.20%	17.16%	17.56%
	Jun	0%	4.17%	6.64%	8.88%	11.62%	12.99%	13.91%	14.71%	15.04%
	Jul	0%	4.39%	7.09%	9.43%	12.39%	13.96%	14.79%	15.77%	16.07%
	Aug	0%	4.16%	6.53%	8.60%	11.39%	12.67%	13.13%	13.84%	14.79%
	Sep	0%	4.67%	7.58%	9.43%	12.98%	14.23%	14.71%	15.44%	16.48%
	Oct	0%	4.95%	7.55%	10.19%	13.32%	14.50%	15.27%	15.55%	16.70%
	Nov	0%	5.09%	7.06%	10.08%	13.05%	13.19%	12.65%	11.09%	19.15%
	Dec	0%	6.59%	9.16%	11.49%	14.13%	10.77%	7.90%	2.63%	23.78%

		East	East 20	East 30	East 40	East 50	East 60	East 70	East 80	East Kinetic

Hue	Jan	0%	6.42%	9.55%	12.63%	16.74%	16.25%	14.56%	13.11%	21.08%
	Feb	0%	6.76%	10.33%	13.67%	17.82%	19.22%	19.22%	20.01%	21.68%
	Mar	0%	5.99%	9.45%	12.21%	16.23%	17.78%	18.70%	19.55%	20.44%
	Apr	0%	4.60%	7.46%	9.81%	12.99%	14.59%	15.21%	15.81%	16.86%
	May	0%	4.10%	6.85%	8.92%	11.87%	13.23%	14.30%	14.87%	15.30%
	Jun	0%	3.75%	6.14%	8.02%	10.67%	11.82%	12.72%	13.22%	13.56%
	Jul	0%	4.24%	6.92%	9.15%	12.13%	13.59%	14.51%	15.26%	15.55%
	Aug	0%	4.11%	6.85%	8.90%	11.68%	13.20%	13.89%	14.45%	15.44%
	Sep	0%	4.17%	6.75%	8.73%	11.57%	12.78%	13.47%	14.09%	14.74%
	Oct	0%	4.53%	7.04%	9.45%	12.32%	13.41%	14.09%	14.71%	15.24%
	Nov	0%	4.58%	6.79%	9.23%	11.99%	12.63%	11.76%	11.13%	15.76%
	Dec	0%	5.63%	8.26%	11.20%	14.67%	14.26%	12.49%	11.71%	19.29%

		East	East 20	East 30	East 40	East 50	East 60	East 70	East 80	East Kinetic
Saigon	Jan	0%	5.92%	8.99%	11.77%	15.66%	17.03%	16.93%	17.55%	20.27%
	Feb	0%	5.44%	8.56%	11.49%	15.28%	17.10%	17.99%	18.93%	19.66%
	Mar	0%	4.69%	7.56%	9.58%	12.94%	14.46%	15.24%	15.87%	16.88%
	Apr	0%	4.29%	7.07%	9.21%	12.20%	13.96%	14.53%	15.36%	16.28%
	May	0%	4.88%	7.86%	10.87%	13.78%	15.50%	16.59%	17.64%	17.88%
	Jun	0%	4.97%	7.98%	10.54%	13.95%	15.51%	16.63%	17.65%	17.90%
	Jul	0%	5.02%	8.06%	10.66%	14.02%	15.60%	16.77%	17.77%	18.08%
	Aug	0%	4.69%	7.76%	10.21%	13.54%	15.43%	15.87%	16.78%	17.77%
	Sep	0%	4.82%	7.75%	10.03%	13.37%	14.94%	15.80%	16.77%	17.42%
	Oct	0%	5.30%	8.57%	11.24%	15.01%	16.40%	17.59%	18.44%	18.93%
	Nov	0%	5.08%	7.79%	10.27%	13.68%	14.85%	14.98%	15.72%	17.84%
	Dec	0%	5.18%	7.78%	10.09%	13.56%	14.24%	14.00%	14.93%	17.58%

Table 7.16 The reduction rate of energy on the Southside for the three cities (%).

		South	South 20	South 30	South 40	South 50	South 60	South 70	South 80	South Kinetic
Hanoi	Jan	0%	8.25%	12.62%	19.72%	22.68%	25.71%	24.28%	25.99%	36.89%
	Feb	0%	9.41%	14.24%	22.36%	26.42%	29.25%	29.19%	31.73%	37.99%
	Mar	0%	6.21%	8.98%	15.03%	17.21%	18.18%	17.66%	18.70%	22.67%
	Apr	0%	2.90%	3.51%	6.81%	7.93%	8.04%	7.80%	8.29%	10.42%
	May	0%	2.23%	2.75%	4.61%	5.87%	6.46%	6.45%	6.84%	7.38%
	Jun	0%	2.25%	2.75%	4.64%	5.94%	6.57%	6.63%	7.22%	7.62%
	Jul	0%	2.14%	2.62%	4.40%	5.61%	6.22%	6.27%	6.74%	7.20%
	Aug	0%	2.33%	2.79%	4.87%	6.13%	6.62%	6.57%	6.90%	8.00%
	Sep	0%	4.00%	6.22%	11.12%	12.31%	13.33%	12.59%	13.65%	14.36%
	Oct	0%	8.62%	12.97%	20.58%	24.08%	27.03%	27.27%	29.73%	30.01%
	Nov	0%	9.61%	14.75%	23.31%	26.98%	30.74%	31.28%	34.54%	37.25%
	Dec	0%	10.30%	16.96%	25.14%	29.58%	33.31%	33.23%	35.66%	41.74%

		South	South 20	South 30	South 40	South 50	South 60	South 70	South 80	South Kinetic

Hue	Jan	0%	11.42%	17.15%	26.96%	31.55%	35.71%	35.70%	39.70%	41.47%
	Feb	0%	11.52%	17.09%	27.27%	32.00%	35.90%	36.01%	38.92%	39.64%
	Mar	0%	5.92%	8.54%	14.93%	17.01%	18.65%	18.20%	19.58%	20.21%
	Apr	0%	1.95%	2.33%	4.07%	5.11%	5.45%	5.17%	5.46%	6.64%
	May	0%	1.60%	2.03%	3.37%	4.26%	4.77%	4.84%	5.25%	5.62%
	Jun	0%	1.33%	1.69%	2.81%	3.60%	4.05%	4.09%	4.37%	4.68%
	Jul	0%	1.26%	1.60%	2.66%	3.41%	3.83%	3.83%	4.11%	4.44%
	Aug	0%	1.51%	1.85%	3.12%	3.84%	4.13%	3.97%	3.91%	5.26%
	Sep	0%	2.53%	4.23%	8.94%	9.16%	9.46%	9.27%	9.99%	10.60%
	Oct	0%	7.42%	11.12%	18.00%	21.07%	23.46%	23.45%	25.55%	25.64%
	Nov	0%	8.61%	12.63%	19.91%	23.64%	26.66%	26.58%	28.90%	31.05%
	Dec	0%	9.82%	14.55%	23.23%	27.23%	30.60%	30.58%	33.19%	36.09%

		South	South 20	South 30	South 40	South 50	South 60	South 70	South 80	South Kinetic
Saigon	Jan	0%	9.57%	14.79%	23.14%	27.22%	30.54%	31.09%	34.04%	34.44%
	Feb	0%	7.72%	12.04%	19.46%	22.48%	24.82%	24.82%	27.06%	27.06%
	Mar	0%	2.48%	4.19%	8.61%	8.74%	8.84%	8.42%	9.13%	9.89%
	Apr	0%	1.50%	1.91%	3.13%	3.94%	4.28%	4.30%	4.15%	5.14%
	May	0%	2.04%	2.58%	4.37%	5.66%	6.30%	6.52%	7.05%	7.31%
	Jun	0%	2.32%	2.88%	4.90%	6.36%	7.10%	7.25%	7.82%	8.14%
	Jul	0%	2.55%	3.13%	5.38%	6.94%	7.75%	7.92%	8.54%	8.92%
	Aug	0%	2.08%	2.59%	4.34%	5.52%	5.99%	6.12%	6.50%	7.47%
	Sep	0%	2.19%	2.72%	5.24%	5.85%	6.44%	6.52%	6.89%	7.56%
	Oct	0%	6.30%	9.73%	16.51%	18.53%	20.18%	19.75%	21.53%	21.70%
	Nov	0%	8.58%	13.13%	20.45%	23.68%	26.72%	26.86%	29.41%	29.97%
	Dec	0%	9.17%	14.07%	22.08%	25.97%	29.29%	29.75%	32.69%	33.11%

Table 7.19, Table 7.20 and Table 7.21 show the percentages of energy saved by each shading aperture scenario compared to the 'no-shading' reference case. Generally speaking, the reductions in energy demand grow with the aperture change; the higher the aperture percentage, the higher is the reduction. The aperture of 80% saves the most, whilst 20% saves the least. However, on these two sides, energy savings are relatively small in wintertime in Hanoi (January – February), because of very low demand for heating or cooling as the average outdoor temperature in these months are around 20 ºC, which are in the thermal comfort zone. Noticeably, when the performance of high apertures (60%, 70% and 80%) is compared to that of 'no-shading' reference case (0%), due to a lack of daylight and solar heat gains and hence requirement for an additional artificial lighting and heating, negative energy savings (energy consumption increase) are seen (-0.37%, -4.93% and -7.18%, respectively).

Reduction trends in energy demand in Hue and Saigon, in contrast, are much more linear. The shading is likely to save more energy in cool seasons in Hue (beginning and the end of the year). In fact, the potential for energy saving is high in those times and low in the summertime due to the outdoor temperature. Understandably, because of constant changes in external temperature over the year, Saigon sees the most linear improvement of energy-saving potential, as it grows along with an increase in shading apertures.

Table 7.21 shows a similar story, but the differences are stronger amplified. Energy savings are much higher for the south-facing offices. The best performing 'fixed case' scenario is 80% aperture with its peak reduction in energy demand of 39.7%, in January in Hue, when compared to 'no-shading' reference case. 29% is the second-highest energy saving, also in Hue but on the west side, and in February. The performance of the 80% aperture is summarised in Table 7.23, which shows occurrence frequency of all apertures.

Table 7.17. Annual energy saving rates in the three sides in the three cities (%).

		Hanoi	Hue	Saigon			Hanoi	Hue	Saigon
20%	West	5.16%	5.43%	5.05%	**60%**	West	15.60%	16.80%	15.61%
	East	4.55%	4.59%	4.99%		East	13.16%	13.90%	15.35%
	South	5.09%	4.92%	5.24%		South	15.79%	15.40%	16.58%
30%	West	7.64%	8.14%	7.54%	**70%**	West	15.20%	16.69%	15.53%
	East	7.02%	7.32%	7.94%		East	13.44%	14.37%	16.02%
	South	7.46%	7.18%	7.86%		South	15.69%	15.32%	16.68%
40%	West	10.89%	11.54%	10.61%	**80%**	West	16.75%	18.50%	17.32%
	East	9.33%	9.63%	10.44%		East	13.72%	14.79%	16.89%
	South	12.10%	11.84%	12.83%		South	16.99%	16.61%	18.16%
50%	West	13.48%	14.30%	13.18%	**Kinetic**	West	18.57%	19.11%	17.57%
	East	12.21%	12.72%	13.84%		East	16.65%	16.27%	17.95%
	South	14.22%	13.85%	14.94%		South	18.91%	17.57%	18.64%

Orientation	Aperture	Hanoi	Hue	Sai Gon
East				
	0			
	0.2	-4.55%	-4.59%	-4.99%
	0.3	-7.02%	-7.32%	-7.94%
	0.4	-9.33%	-9.63%	-10.44%
	0.5	-12.21%	-12.72%	-13.84%
	0.6	-13.16%	-13.90%	-15.35%
	0.7	-13.44%	-14.37%	-16.02%
	0.8	-13.72%	-14.79%	-16.89%
	Kinetic	-16.65%	-16.27%	-17.95%
South				
	0			
	0.2	-5.09%	-4.92%	-5.24%
	0.3	-7.46%	-7.18%	-7.86%
	0.4	-12.10%	-11.84%	-12.83%
	0.5	-14.22%	-13.85%	-14.94%
	0.6	-15.79%	-15.40%	-16.58%
	0.7	-15.69%	-15.32%	-16.68%
	0.8	-16.99%	-16.61%	-18.16%
	Kinetic	-18.91%	-17.57%	-18.64%
West				
	0			
	0.2	-5.16%	-5.43%	-5.05%
	0.3	-7.64%	-8.14%	-7.54%
	0.4	-10.89%	-11.54%	-10.61%
	0.5	-13.48%	-14.30%	-13.18%
	0.6	-15.60%	-16.80%	-15.61%
	0.7	-15.20%	-16.69%	-15.53%
	0.8	-16.75%	-18.50%	-17.32%
	Kinetic	-18.57%	-19.11%	-17.57%

Figure 7.21. Annual energy saving percentage rates in three cities. (Source: Author).

The kinetic scenario proposed in this research, performs better than any fixed aperture case, in all cities and for all orientations (see Table 7.17). Figure 7.21 shows the absolute percentages of annual average energy demand reduction of the apertures, including the kinetic case, in comparison with the 'no-shading' reference case. The operation of the proposed kinetic shading device is defined as a combination of all hourly 'best-fixed' façade apertures, which at its peak has a maximum of 19.11% (Hue, Westside) energy reduction percentage and a minimum of 16.27% (Hue, Eastside) per year. These figures for the 'best-fixed' 80% aperture façade are 18.5% (Hue, Westside) and 13.72% (Hue, Eastside), respectively. It is important to be cautious with percentage reduction metrics, i.e. they could be misleading in terms of the fact that the total absolute reduction in kWh/m^2 could be higher even if the percentage is lower.

Table 7.18. Annual frequency occurrence of eight apertures. (Source: Author).

		West								East								South							
		Ref	20%	30%	40%	50%	60%	70%	80%	Ref	20%	30%	40%	50%	60%	70%	80%	Ref	20%	30%	40%	50%	60%	70%	80%
Hanoi	Jan	107	26	24	28	37	30	14	34	101	22	23	30	20	22	16	55	101	22	23	30	20	22	16	55
	Feb	116	21	20	22	26	22	11	53	113	20	20	20	20	15	14	62	113	20	20	20	20	15	14	62
	Mar	103	33	16	18	32	24	17	82	111	32	15	14	44	20	13	72	111	32	15	14	44	20	13	72
	Apr	47	23	16	18	31	30	14	119	58	23	16	30	43	21	11	89	58	23	16	30	43	21	11	89
	May	20	18	18	24	19	22	27	144	37	19	20	20	17	23	19	98	37	19	20	20	17	23	19	98
	Jun	25	19	18	27	19	20	22	169	30	27	22	19	24	28	15	126	30	27	22	19	24	28	15	126
	Jul	27	22	20	35	23	18	28	155	31	35	23	20	26	28	22	114	31	35	23	20	26	28	22	114
	Aug	25	19	18	27	22	36	19	137	43	21	19	20	45	22	22	102	43	21	19	20	45	22	22	102
	Sep	26	19	20	23	34	45	30	129	40	20	19	43	31	34	18	120	40	20	19	43	31	34	18	120
	Oct	25	18	18	25	24	36	23	127	27	18	18	19	29	20	32	132	27	18	18	19	29	20	32	132
	Nov	51	22	23	25	39	45	36	90	56	21	23	26	26	30	20	122	56	21	23	26	26	30	20	122
	Dec	94	44	46	44	84	48	34	60	83	30	40	35	36	52	23	87	83	30	40	35	36	52	23	87
Hue	Jan	44	37	36	37	51	51	29	29	99	31	32	35	51	45	31	45	36	30	30	40	36	39	25	107
	Feb	40	35	34	36	38	35	21	135	54	33	30	39	44	35	14	89	37	33	32	29	35	29	27	122
	Mar	30	25	24	24	33	42	23	170	47	25	24	27	43	26	39	133	36	28	24	52	30	26	22	151
	Apr	22	21	21	22	28	46	20	151	42	21	21	23	39	29	51	85	42	22	21	21	39	34	16	102
	May	21	21	19	22	19	33	20	149	38	19	19	19	34	14	49	83	40	19	26	19	31	14	13	107
	Jun	22	22	22	22	24	29	22	189	41	22	22	22	27	39	50	100	41	22	22	22	29	43	26	147
	Jul	23	22	22	29	25	23	24	185	42	22	22	22	27	36	45	106	42	22	22	22	28	44	25	144
	Aug	20	20	20	21	34	47	22	136	40	20	20	20	37	22	48	90	47	20	46	28	28	32	28	72
	Sep	22	22	22	22	22	22	22	175	44	22	22	42	24	31	33	111	35	22	22	64	23	33	22	131
	Oct	21	20	20	21	24	25	19	164	25	35	20	20	25	37	18	126	20	20	20	20	30	32	17	155
	Nov	35	23	23	26	43	45	22	116	49	25	21	25	41	43	36	73	37	33	21	24	41	33	20	121
	Dec	51	28	28	36	50	47	25	100	62	26	25	32	52	39	18	74	51	27	25	28	40	41	19	111
Sai Gon	Jan	20	18	18	19	20	44	42	108	41	19	30	18	20	48	16	74	21	18	18	20	35	19	18	139
	Feb	20	20	20	20	20	20	20	180	40	20	20	21	23	37	38	121	21	20	20	20	20	21	20	178
	Mar	23	23	23	23	23	47	23	183	46	23	23	23	46	23	46	138	42	23	23	46	35	25	23	151
	Apr	21	21	21	21	21	42	21	168	42	21	21	21	42	21	41	125	42	21	21	42	21	21	74	74
	May	19	19	19	23	19	28	19	158	38	19	19	19	19	38	19	133	38	19	19	19	38	19	19	133
	Jun	22	22	22	22	24	36	22	182	44	22	22	22	27	36	25	154	44	22	22	22	26	40	22	154
	Jul	22	22	22	22	24	22	22	176	43	22	22	22	28	27	34	154	43	22	22	22	26	41	22	154
	Aug	20	20	20	21	20	39	20	160	40	20	20	20	26	34	37	122	40	20	20	24	36	20	21	139
	Sep	22	22	22	22	23	43	22	176	44	22	22	22	44	22	36	132	44	22	22	22	26	35	29	109
	Oct	20	20	20	20	20	21	20	179	29	20	23	20	43	35	22	120	21	20	20	20	42	20	20	157
	Nov	21	21	21	22	40	40	21	150	62	21	21	21	24	45	19	103	30	21	40	22	22	22	40	139
	Dec	22	22	22	26	23	61	27	149	66	22	22	22	44	33	18	86	23	23	22	42	23	24	22	173

7.5.4 Summary

In summary, in terms of location, the shading device performs best in Saigon, where both cooling loads and light levels are at their highest. Saigon has the average peak reduction in energy demand of all apertures, 13.19% on the south-facing side, followed by 13.06% for Hue, on the west-facing side. Regarding the orientations, the maximum average reduction in energy demand is seen on the west side (18.42%), followed by 18.37% (south side) and 16.96% (east side). Outdoor temperature plays the most significant role in driving energy reduction with shading apertures, as the lighting gains due to high percentage shading aperture ratios are relatively modest. Table 7.23 shows that 80% aperture has the highest occurrence frequency in Saigon, for all three orientations. Given that Saigon climate requires only cooling this is to be expected. Similar behaviour can be observed for Hue, although in Dec and Jan with a lot more even spread. On one occasion, in Jan in Hue on the east side, no-shading has a higher frequency than any aperture shading scenarios, likely to be due to the benefits of solar gains in the winter. This behaviour is clearly observed in Hanoi during the winter months of (Dec-

Mar), where again the benefit in terms of energy reduction due to solar gains of a 'no-shading' scenario outweighs the others, giving it the highest frequency of occurrence.

It is important to note that analysis in this section is concerned with a single objective of reduction in energy demands only, as it was the case with the daylight levels in the section before. Hence the extreme cases of solar shading apertures were favoured as solutions by the simulation analysis. Section 7.5.5 explains what happens when both of those objectives are considered concurrently.

7.5.5 Optimisation - Statistical Normalisation and Weighting Factor

The essential advantage of the conventional design method is that the designer's knowledge and sensitivity can be used in formulating conceptual changes in the system. For instance, designers may select either vertical or horizontal shading louvres, and add or remove a number of components to configure different shading apertures, and so on. However, the conventional design process may lead to ineffective designs and can be labour intensive due to its 'trial and error' approach. In the conventional design, an objective function that measures the device's performance is not directly considered. Performance data trends are not analysed, and hence there is no real planning for design decisions in terms of improving and refining the system.

On the contrary, optimisation is a methodical process that seeks improved and refined solutions in its quest to maximise or minimise the design objectives. In addition, it is beneficial for the designer's experience in framing the problem and recognising the crucial restraints.

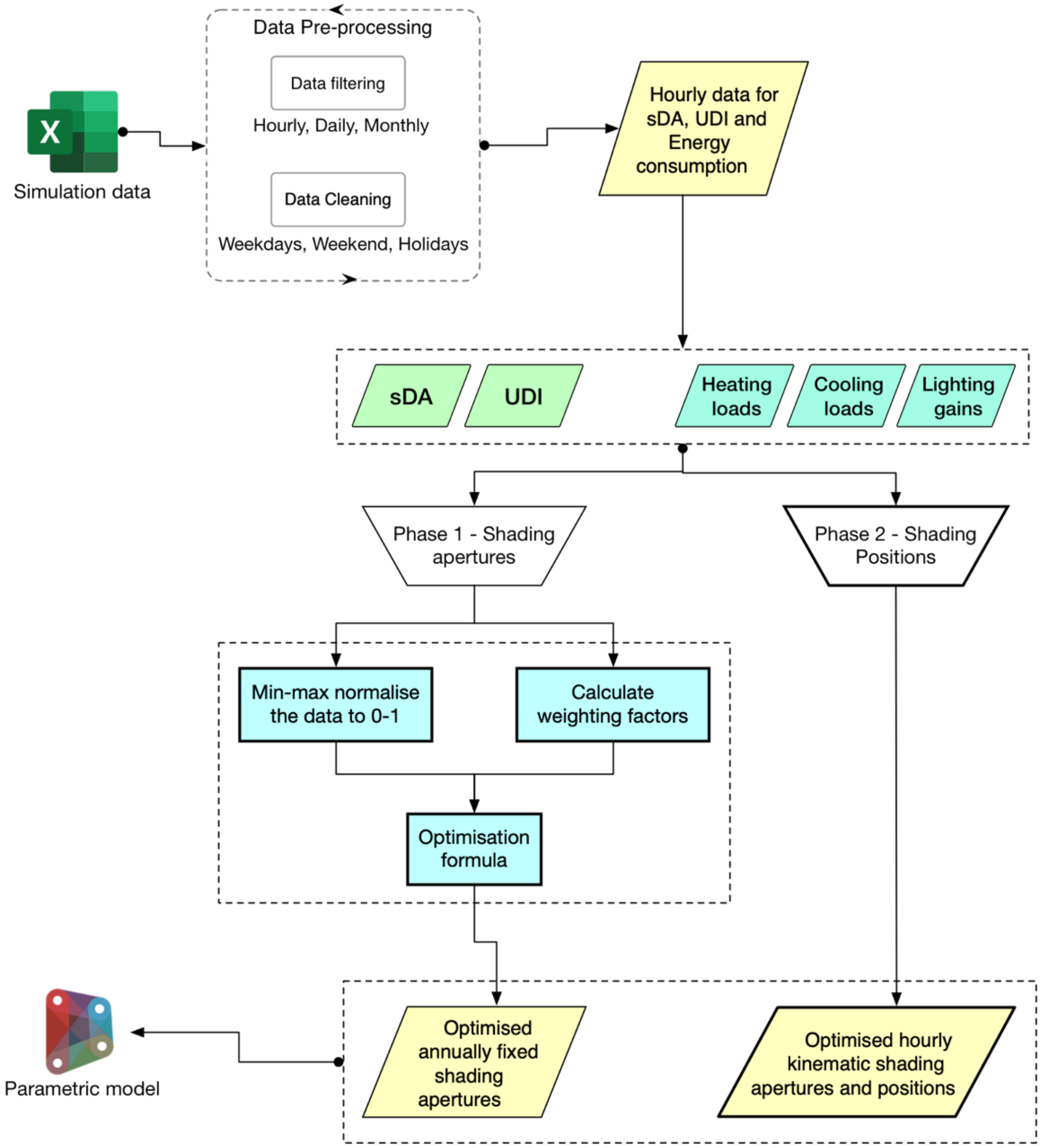

Figure 7.22 Framework for shading aperture optimisation. (Source: Author).

Figure 7.22 illustrates the workflow of an optimisation framework developed in this research to optimise façade apertures performance. Firstly, two critical sets of data for daylighting level (DL) and energy demand savings (ES) from previous simulations are exported into spreadsheets format – Excel's .xmls format. The data is then filtered and 'cleaned up', as there are 8760 hours in a full year, which means there also are 8760 rows of data in each spreadsheet. However, not all of them are useful, for example, weekends and holidays and rows of before and after working hours. These rows need to be eliminated. As a result, two clean sets (with 2250 rows in each file) are created.

The framework simplifies the above mentioned multiple-objective optimisation problem to a weighted-sum single-objective optimisation. The process involves two phases: (i) Phase 1 – conduct search for an optimised annual fixed shading aperture through a min-max normalisation and weighting factors calculation techniques. This is needed as daylight levels and energy demand have different value ranges, units and scales which must be mapped into one neutral range to make valid comparisons; and (ii) Phase 2 - finds hourly best apertures for the whole year to formulate a set of data for the dynamic (kinetic) shading system. These two phases achieve two new datasets which are then imported into BIM visual programming environment for computational control of the kinetic facade system operation.

7.5.5.1 Min-max Normalisation

Normalisation is a scaling or mapping technique of a pre-processing stage, where a new range can be created from a standing array (Griffioen, 2003). Min-Max normalisation (MN) is a technique in data science that accomplishes a linear transformation on the given range. In fact, it scales value a of a pre-defined data range R = [min(r), max(r)] to a new value a' in the new range R' = [new min(r), new max(r)]. MN is formulated as follow:

$$a' = \frac{[a-min(r)]*[new\max(r)-new\min(r)]}{max(r)-min(r)} + new\min(r) \qquad 7.1$$

In this research, MN maps $a \in$ R =[max(DL/EC), min(DL/EC], into $a' \in$ R'= [0,1] – the neutral range; thus, set new min(r) = 0 and new max(r) = 1 for the above equation, it now becomes a simplified formula as follow:

$$a' = \frac{a-min(r)}{max(r)-min(r)} \qquad 7.2$$

Notably, the Min-Max normalisation conserves the relationship between all values of the pre-defined data array. In the case of DL, new max (DL) = 1, which means that the highest value of DL in the range from aperture 0%'s value to aperture 80%'s value. For instance, the highest value in the array data of sDA for the Westside office in Hanoi - 38.18% (0%) (see Table 7.19) will be mapped to 1. In contrast, the lowest value in this range – 14.55% (80%) will be mapped to 0.

Table 7.19. Annual statistics of daylight and energy consumptions for the three cities.

Space ID	Hanoi	Hue	Saigon	Hanoi	Hue	Saigon	Hanoi	Hue	Saigon
	sDA (%)			UDI (%)			ES (%)		
West 0	38.18	52.95	67.95	100.00	100.00	100.00	0.00	0.00	0.00
West 20	34.55	40.23	49.09	95.50	100.00	100.00	5.16	5.43	5.05
West 30	27.50	36.82	42.95	70.20	100.00	100.00	7.64	8.14	7.54
West 40	23.86	28.64	36.14	58.20	97.00	100.00	10.89	11.54	10.61
West 50	23.64	23.64	28.86	49.50	68.90	99.50	13.48	14.30	13.18
West 60	21.36	23.64	24.32	37.50	50.50	63.20	15.60	16.80	15.61
West 70	20.23	22.50	23.86	36.80	42.80	57.50	15.20	16.69	15.53
West 80	14.55	16.14	22.95	28.20	34.80	44.50	16.75	18.50	17.32
East 0	46.74	58.26	70.30	100.00	99.30	98.70	0.00	0.00	0.00
East 20	43.70	48.40	57.39	87.40	100.00	100.00	4.55	4.59	4.99
East 30	35.65	44.35	50.30	73.30	100.00	100.00	7.02	7.32	7.94
East 40	34.78	39.78	46.96	66.10	82.80	100.00	9.33	9.63	10.44
East 50	31.25	34.78	36.52	56.10	67.80	89.60	12.21	12.72	13.84
East 60	31.52	31.44	35.22	46.50	57.40	68.50	13.16	13.90	15.35
East 70	26.96	30.65	33.26	44.30	50.90	58.50	13.44	14.37	16.02
East 80	25.65	26.90	32.61	36.50	45.70	50.00	13.72	14.79	16.89
South 0	35.23	46.14	51.82	100.00	100.00	100.00	0.00	0.00	0.00
South 20	27.73	35.68	43.41	68.20	100.00	100.00	5.09	4.92	5.24
South 30	24.55	35.00	36.82	60.70	100.00	100.00	7.46	7.18	7.86
South 40	23.64	24.77	27.50	49.30	70.50	99.30	12.10	11.84	12.83
South 50	34.57	34.57	35.22	55.00	66.50	78.30	14.22	13.85	14.94
South 60	22.95	23.64	23.64	35.70	46.60	57.30	15.79	15.40	16.58
South 70	32.39	34.35	34.57	44.80	54.10	59.80	15.69	15.32	16.68
South 80	13.18	19.90	23.41	24.50	34.80	43.40	16.99	16.61	18.16

For example, let's take a sDA value for West 40% shading scenario in Hanoi - 23.86% to calculate normalised value:

$$a' = \frac{23.86\% - 14.55\%}{38.18\% - 14.55\%} = 0.39 \qquad 7.3$$

Thus, the value of the West 40 aperture in Hanoi is normalised to MN_{W40H} = 0.39, as seen in Table 7.20. Table 7.20 shows normalised values for sDA, UDI and ES.

Table 7.20. MN data for sDA, UDI and Loads.

Space ID	Hanoi			Hue			Saigon		
	sDA	UDI	ES	sDA	UDI	ES	sDA	UDI	ES
West 0	1	1	1	1	1	1	0	0	0
West 20	0.85	0.94	0.69	0.65	1.00	0.71	0.31	0.29	0.29
West 30	0.55	0.58	0.54	0.56	1.00	0.56	0.46	0.44	0.44
West 40	0.39	0.42	0.35	0.34	0.95	0.38	0.65	0.62	0.61
West 50	0.38	0.30	0.20	0.20	0.52	0.23	0.80	0.77	0.76
West 60	0.29	0.13	0.07	0.20	0.24	0.09	0.93	0.91	0.90
West 70	0.24	0.12	0.09	0.17	0.12	0.10	0.91	0.90	0.90
West 80	0	0	0	0	0	0	1	1	1
East 0	1	1	1	1	0.99	0.97	0	0	0
East 20	0.86	0.69	0.66	0.80	1	1	0.33	0.31	0.33
East 30	0.47	0.56	0.47	0.58	1	1	0.51	0.49	0.51
East 40	0.43	0.41	0.38	0.47	0.68	1.00	0.68	0.65	0.68
East 50	0.27	0.25	0.10	0.31	0.41	0.79	0.89	0.86	0.89
East 60	0.28	0.14	0.07	0.16	0.22	0.37	0.96	0.94	0.96
East 70	0.06	0.12	0.02	0.12	0.10	0.17	0.98	0.97	0.98
East 80	0	0	0	0	0	0	1	1	1
South 0	1	1	1	1	1	1	0	0	0
South 20	0.66	0.60	0.70	0.58	1	1	0.30	0.30	0.29
South 30	0.52	0.58	0.47	0.48	1	1	0.44	0.43	0.43
South 40	0.47	0.19	0.14	0.33	0.55	0.99	0.71	0.71	0.71
South 50	0.97	0.56	0.42	0.40	0.49	0.62	0.84	0.83	0.82
South 60	0.44	0.14	0.01	0.15	0.18	0.25	0.93	0.93	0.91
South 70	0.87	0.55	0.39	0.27	0.30	0.29	0.92	0.92	0.92
South 80	0	0	0	0	0	0	1	1	1

The same is done for the UDI and ES. Finally, Table 7.20 has a list of all of the normalised value for sDA, DL and ES, representing overall performances of each objective. Next step is to find their weight (or importance).

7.5.5.2 Weighting Factors

Weighting factors (WFs) are used to measure the importance of the objectives. In this phase, WFs for sDA, UDI and ES need to be calculated, hereafter referred to as WF_{sDA}, WF_{UDI}, WF_{ES}. Following equations are used to find the fit value of the weighting factors considering the three objectives:

$$WF_{sDA} + WF_{UDI} + WF_{ES} = 1 \tag{7.4}$$

$$L_{sDA} * WF_{sDA} = L_{UDI} * WF_{UDI} = L_{ES} * WF_{ES} \tag{7.5}$$

where L is the length of the ranges or distances between the largest and the smallest value in a given range for the cities. For example, a range of sDA is: R_{sDA} = [value of West 0, value of West 80]

$$L_{sDA} = \textit{value of}\text{ West }80\% - \textit{value of}\text{ West }0\% \qquad 7.6$$

Table 7.21 list values of L_{sDA}, L_{UDI} and L_{ES} based on Equations 7.6 and data shown in Table 7.19.

Table 7.21 The lengths of ranges.

	Hanoi			Hue			Saigon		
	L_{sDA}	L_{UDI}	L_{ES}	L_{sDA}	L_{UDI}	L_{ES}	L_{sDA}	L_{UDI}	L_{ES}
West	23.63	71.80	11.59	36.81	65.20	13.70	45.00	55.50	12.27
East	21.09	63.50	9.17	31.36	54.30	10.20	37.69	54.30	11.90
South	38.64	75.50	11.90	26.24	65.20	11.69	28.11	56.60	12.92

Equations 7.4 and 7.5 calculates weighting factors:

$$WF_{sDA} = L_{sDA} / (L_{sDA} + L_{UDI} + L_{ES}) \qquad 7.7$$

$$WF_{UDI} = L_{UDI} / (L_{sDA} + L_{UDI} + L_{ES}) \qquad 7.8$$

$$WF_{ES} = L_{ES} / (L_{sDA} + L_{UDI} + L_{ES}) \qquad 7.9$$

Table 7.22. Weighting Factors of sDA, UDI and EC.

	Hanoi			Hue			Saigon		
	sDA	UDI	ES	sDA	UDI	ES	sDA	UDI	ES
West	0.22	0.67	0.11	0.32	0.56	0.12	0.40	0.49	0.11
East	0.22	0.68	0.10	0.33	0.57	0.10	0.36	0.52	0.12
South	0.30	0.60	0.10	0.25	0.63	0.12	0.29	0.57	0.14

Weighting factors values are specified in Table 7.22 using formulas 7.7-7.9. These numbers are used in conjunction with min-max normalisation values in Table 7.20 to generate a new set of data, which is a combination of these two, to estimate each aperture's individual performance for the three objectives. Specifically, the normalised values are multiplied by the weighting factors. For example, $MN_{W40H} * WF_{sDA-WH} = 0.39 * 0.22 = 0.09$ (see Table 7.23).

Table 7.23 Combined values of MN and WF.

Space ID	Hanoi			Hue			Saigon		
	sDA	UDI	EC	sDA	UDI	EC	sDA	UDI	EC
West 0	0.22	0.67	0.11	0.32	0.56	0.12	0	0	0
West 20	0.19	0.63	0.08	0.21	0.56	0.09	0.12	0.14	0.03
West 30	0.12	0.39	0.06	0.18	0.56	0.07	0.18	0.22	0.05
West 40	0.09	0.28	0.04	0.11	0.53	0.05	0.26	0.30	0.07
West 50	0.08	0.20	0.02	0.06	0.29	0.03	0.32	0.38	0.08
West 60	0.06	0.09	0.01	0.06	0.13	0.01	0.37	0.45	0.10
West 70	0.05	0.08	0.01	0.05	0.07	0.01	0.36	0.44	0.10
West 80	0	0	0	0	0	0	0.40	0.49	0.11
East 0	0.22	0.68	0.10	0.33	0.56	0.10	0	0	0
East 20	0.19	0.47	0.07	0.26	0.57	0.10	0.12	0.16	0.04
East 30	0.10	0.38	0.05	0.19	0.57	0.10	0.18	0.25	0.06
East 40	0.09	0.28	0.04	0.16	0.39	0.10	0.24	0.34	0.08
East 50	0.06	0.17	0.01	0.10	0.23	0.08	0.32	0.45	0.11
East 60	0.06	0.10	0.01	0.05	0.13	0.04	0.35	0.49	0.12
East 70	0.01	0.08	0.00	0.04	0.06	0.02	0.35	0.50	0.12
East 80	0	0	0	0	0	0	0.36	0.52	0.12
South 0	0.30	0.60	0.10	0.25	0.63	0.12	0	0	0
South 20	0.20	0.36	0.07	0.15	0.63	0.12	0.09	0.17	0.04
South 30	0.16	0.35	0.05	0.12	0.63	0.12	0.13	0.25	0.06
South 40	0.14	0.11	0.01	0.08	0.35	0.12	0.21	0.40	0.10
South 50	0.29	0.34	0.04	0.10	0.31	0.07	0.24	0.47	0.11
South 60	0.13	0.08	0.00	0.04	0.11	0.03	0.27	0.53	0.13
South 70	0.26	0.33	0.04	0.07	0.19	0.03	0.27	0.52	0.13
South 80	0	0	0	0	0	0	0.29	0.57	0.14

The final step is to summarise the overall performance of each aperture in each of the cities and for each orientation. Table 7.24 demonstrates the data ranges of the eight apertures, unified into a single integrated result, showing which aperture produces the most comprehensive performance. These optimised results are calculated in the form of normalised data, varying between 0 and 1.

Table 7.24. Integrated performance - Optimal aperture for the best static façade.

	Hanoi	Hue	Saigon
West 0	1	1	0
West 20	0.89	0.85	0.30
West 30	0.57	0.81	0.45
West 40	0.41	0.69	0.63
West 50	0.31	0.38	0.78
West 60	0.16	0.21	0.92
West 70	0.14	0.13	0.90
West 80	0	0	1

Avg	**0.43**	**0.51**	**0.62**
East 0	1.00	0.99	0.00
East 20	0.72	0.93	0.32
East 30	0.53	0.86	0.50
East 40	0.41	0.64	0.66
East 50	0.24	0.42	0.87
East 60	0.16	0.22	0.95
East 70	0.10	0.11	0.97
East 80	0.00	0.00	1.00
Avg	**0.40**	**0.52**	**0.66**
South 0	1.00	1.00	0.00
South 20	0.63	0.90	0.30
South 30	0.55	0.87	0.43
South 40	0.27	0.55	0.71
South 50	0.67	0.48	0.83
South 60	0.22	0.18	0.93
South 70	0.63	0.29	0.92
South 80	0.00	0.00	1.00
Avg	**0.50**	**0.53**	**0.64**

The purpose of optimising the façade design is to find the optimal point for both daylight provision and energy consumption, the solution which, in a given domain range, maximises daylight whilst minimizing the energy consumption. The optimal value is chosen if the value of the cumulative result is the closest to the integrated average value (see Table 7.29). The aperture of 40% is the annual 'best-fixed' solution almost everywhere, being chosen six out of nine times (Saigon on all three sides, Hanoi on both the west and east side and Hue on the south side). 50% is chosen twice as the best for Hue on the east and west side, whilst 30% is chosen once for Hanoi's south-facing offices.

Overall, these winning apertures are the ones which neither have the best daylight performance nor those that minimise energy demands. Instead, they deliver at the optimal medium rate to maintain a high quality of natural light within the office whilst contributing significantly to the reduction in energy demands. On the final note, large apertures, such as 70% and 80%, save the most energy but on the expense of daylight levels which are very low, whilst small apertures offer high levels of natural light but low energy savings.

7.6 Phase 2 – Define the Kinetic Shading Performance

The final remaining step is to determine a difference between the best-fixed façade and proposed kinetic version. As demonstrated in the last stage, a range of mid-opening apertures

- 40%, 50% and 60%, with their five discrete shading compositions, will be used in the analysis. This time, the hourly performance of energy consumption is the main objective. Multiple-objective optimisation now becomes single-objective optimisation, which is merely a direct minimising process. As such, three apertures in five compositions (up, up left, down, downright and evenly distributed) are simulated, on an hourly basis.

Simulation data of the 15 combinations (3 apertures x 5 compositions) are filtered and cleaned in Excel spreadsheets. Minimum values are established in the last column (Kinetic). An example of the aperture 60% is shown in Figure 7.23. Overall, the evenly distributed composition of shading pattern provides the most of optimal hourly values.

A	B	C	D	E	F	G	H
Date	Time	60% Up Left	60% Down Right	60% Down	60% Up	60% Evenly Distribu	60% KINETIC
				Loads (W)			
Mon, 04/Jan	09:30	0.1166	0.1166	0.1166	0.1308	0.1166	0.1166
Mon, 04/Jan	10:30	0.1102	0.1022	0.1022	0.1022	0.1022	0.1022
Mon, 04/Jan	11:30	0.6013	0.9999	0.9788	0.5913	0.592	0.5913
Mon, 04/Jan	12:30	1.9512	2.3723	2.3594	1.9513	1.9576	1.9512
Mon, 04/Jan	13:30	0.0965	0.0965	0.0965	0.0965	0.0965	0.0965
Mon, 04/Jan	14:30	6.2931	8.6425	8.4611	6.1801	6.5586	6.1801
Mon, 04/Jan	15:30	3.747	4.8321	4.7897	3.8146	3.9356	3.747
Mon, 04/Jan	16:30	2.9652	2.7151	2.8045	3.2411	2.865	2.7151
Mon, 04/Jan	17:30	2.445	2.2942	2.3788	2.4829	2.4112	2.2942
Tue, 05/Jan	09:30	0.7112	0.243	0.3267	0.7761	0.6387	0.243
Tue, 05/Jan	10:30	0.2392	0.1022	0.1022	0.302	0.1853	0.1022
Tue, 05/Jan	11:30	0.1905	0.3007	0.2942	0.1925	0.1877	0.1877
Tue, 05/Jan	12:30	1.3009	1.6614	1.645	1.3052	1.3007	1.3007
Tue, 05/Jan	13:30	0.0965	0.0965	0.0965	0.0965	0.0965	0.0965
Tue, 05/Jan	14:30	6.0772	8.2567	8.08	6.0288	6.3008	6.0288
Tue, 05/Jan	15:30	4.5901	4.9364	4.9675	4.678	4.6762	4.5901
Tue, 05/Jan	16:30	3.8579	3.3128	3.5295	4.0145	3.7892	3.3128
Tue, 05/Jan	17:30	2.5795	2.4843	2.5375	2.5942	2.5636	2.4843
Wed, 06/Jan	09:30	0.1774	0.1166	0.1166	0.2986	0.1245	0.1166
Wed, 06/Jan	10:30	0.1022	0.1022	0.1022	0.1022	0.1022	0.1022
Wed, 06/Jan	11:30	0.4477	0.628	0.6005	0.5551	0.4037	0.4037
Wed, 06/Jan	12:30	0.7925	0.3737	0.3573	0.9068	0.6818	0.3573
Wed, 06/Jan	13:30	0.3822	0.0965	0.0965	0.4622	0.3091	0.0965
Wed, 06/Jan	14:30	2.6323	2.7128	2.6672	2.8324	2.5077	2.5077
Wed, 06/Jan	15:30	2.7016	2.3686	2.4237	2.8632	2.6168	2.3686
Wed, 06/Jan	16:30	2.9839	2.4884	2.6574	3.0746	2.9164	2.4884
Wed, 06/Jan	17:30	2.3122	2.3154	2.329	2.3142	2.3119	2.3119
Thu, 07/Jan	09:30	0.211	0.1166	0.1166	0.4373	0.1276	0.1166
Thu, 07/Jan	10:30	0.9513	0.9285	0.9267	1.0503	0.8125	0.8125
Thu, 07/Jan	11:30	2.4542	2.4651	2.4646	2.4746	2.3825	2.3825
Thu, 07/Jan	12:30	2.7466	3	2.9937	2.7628	2.782	2.7466
Thu, 07/Jan	13:30	0.0965	0.0965	0.0965	0.0965	0.0965	0.0965
Thu, 07/Jan	14:30	6.991	9.2918	9.1112	6.8797	7.2609	6.8797
Thu, 07/Jan	15:30	4.3339	5.3801	5.3399	4.4771	4.5046	4.3339
Thu, 07/Jan	16:30	3.523	3.2325	3.3212	3.8053	3.4164	3.2325
Thu, 07/Jan	17:30	2.5848	2.3995	2.4915	2.6328	2.5468	2.3995
Fri, 08/Jan	09:30	0.2151	0.1166	0.1166	0.4193	0.12	0.1166
Fri, 08/Jan	10:30	1.1179	1.2603	1.2483	1.2949	1.0429	1.0429
Fri, 08/Jan	11:30	2.8232	2.9732	2.964	2.8233	2.7932	2.7932
Fri, 08/Jan	12:30	3.3229	3.6268	3.6128	3.3252	3.3358	3.3229
Fri, 08/Jan	13:30	0.0965	0.0965	0.0965	0.0965	0.0965	0.0965
Fri, 08/Jan	14:30	6.7466	8.3427	8.2166	6.6699	6.9248	6.6699
Fri, 08/Jan	15:30	4.3343	4.5975	4.5999	4.4778	4.3511	4.3343
Fri, 08/Jan	16:30	4.0735	3.5456	3.722	4.1903	3.9974	3.5456

WEST | EAST | SOUTH | WEST BEST KIN | Sheet4 | Sheet5 | EAST BEST KIN | SOUTH

Figure 7.23 Example of comparison of different shading system composition (up left, downright, down, up, evenly distributed) with 60% aperture coverage. (Source: Author) .

7.7 System Evaluation and Discussion

Throughout this research, the system development and its frameworks have proved that shape grammar emergence concept can lead to an abundant amount of kinetic façade shading design possibilities. To prove that those proposed kinetic shading devices can have not just a cultural benefit in terms of their design, but environmental and with its economic benefit too; a base case (no shading) of office space and its seven distinct façade apertures have been simulated, in three representative Vietnamese cities and for three orientations. In total, 72 design options were analysed. In summary, annual reduction rates of the kinetic façade and the fixed one are compared in Table 7.25.

Table 7.25 Comparison of reduction rates between the best-fixed façades and kinetic facades and the unshaded (Ref.) ones.

		Hanoi			**Hue**			**Saigon**		
		Best fixed	**Kinetic**	Ref.	Best fixed	**Kinetic**	Ref.	Best fixed	**Kinetic**	Ref.
West	Energy demand (kWh/m^2)	10030.52	9295.93	11255.95	13074.33	12126.93	14779.38	15600.07	14622.70	17452.01
	Reduction rate (%)	10.89%	**17.41%**	0%	11.54%	**17.95%**	0%	10.61%	**16.21%**	0%
	Absolute Difference (kWh/m^2)	1225.44	1960.02	0%	1705.05	2652.46	0%	1851.94	2829.31	0%
East	Energy demand (kWh/m^2)	9791.90	9132.56	10799.85	12206.37	11742.81	13984.82	15695.78	14718.26	17524.40
	Reduction rate (%)	9.33%	**15.44%**	0%	12.72%	**16.03%**	0%	10.43%	**16.01%**	0%
	Absolute Difference (kWh/m^2)	1007.95	1667.29	0%	1778.45	2242.01	0%	1828.62	2806.14	0%
South	Energy demand (kWh/m^2)	9706.04	9503.38	11512.67	12549.42	12104.40	14567.22	15907.63	15003.09	18247.88
	Reduction rate (%)	15.69%	**17.45%**	0%	13.85%	**16.91%**	0%	12.82%	**17.78%**	0%
	Absolute Difference (kWh/m^2)	1806.63	2009.29	0%	2017.80	2462.82	0%	2340.24	3244.79	0%

Significant reductions in energy demand are observed for a proposed dynamic shading system, saving from 15.44% to 17.95% energy, compared to the base case (no shading), whilst the 'best-fixed' shading case saves from 9.33% to 15.69%. The proposed kinetic shading system has an average of 4.5% higher reduction in energy demands than its 'best-fixed 'counterpart, with a maximum of 6.52% (Hanoi, west) and a minimum 1.76% (Hanoi, south). The total saving for three orientations with kinetic shading device is 50.89% for Hue, 50% for Saigon, and 50.3% for Hanoi, compared to 'no-shading' scenario.

The maximum annual ES of 17.78% is seen in the Saigon' South office with the kinetic façade consumes 150003 kW, which is 3245 kW less than the energy utilised by the reference case (18248 kW), while the energy expenditure of the best-fixed façade is 15908 kW, saving 2340 kW around the year. Noticeably, this maximum save comes from the largest amount of energy consumption. The minimum saves, in contrast, comes from the smallest EC of Hanoi's

East office as the kinetic and the best-fixed façade help reduce 1667 kW and 1008 kW, respectively.

7.8 Chapter Summary

This chapter determined a multi-phase framework to deal with several conflicting objectives. In the framework, a simulation and a multi-objective optimisation approach were planned to attain thorough information on configurations of shading apertures and positions. The thermodynamic and lighting simulations were performed aiming at the data of annual energy demands for heating, cooling and artificial lighting, and carried out for an open plan working space, facing towards the North, South, and West, by differing five shading positions and eight shading apertures of the external facades. For the case study, the analyses were conducted in the presence of an urban context in three Vietnamese cities, which are Hanoi, Hue, and Saigon; the tool used was IES-VE. The procedure resulted in a big dataset, which was managed further in spreadsheet format to produce a Pareto front (of 360 candidates).

Based on the Pareto fronts, a multi-objective optimisation was implemented using statistical methods of Min-max normalisation and Weighting factors, performed against the Key performance indicators. Results from the analysis of 72 candidates confirmed the configurations of best-fixed candidates. This vital stage allowed for a comprehensive comparison between a proposed kinetic shading devices and the 'best-fixed' one. Enhanced performance of the KiSS shading devices and their statistical findings are explained in section 7.5.4 and 7.7.

CHAPTER 8: BIM-INTEGRATED REAL-TIME PERFORMANCE MONITORING AND EVALUATION

8.1 BIM– SDA – SBE Integration

Asset monitoring and evaluating the performance of a building compared to its simulated performance through sustainable design analysis (SDA), is implemented through building management systems (BMS). Automating this process through programming and system optimisation leads to intelligent and dynamic buildings, or smart building environments (SBEs), sufficiently 'smart' to intelligently control building energy consumption whilst providing a comfort and support for their users (see Fig 8.1), with facades for example that can adapt to the environmental conditions both around and within the building, in the real-time.

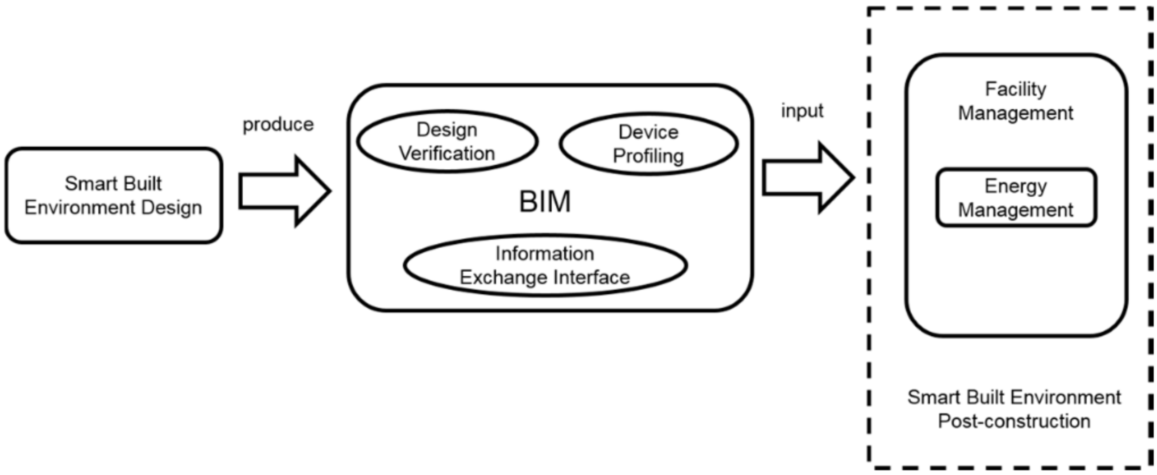

Figure 8.1. Model of BIM-integrated smart built environments (Zhang et al., 2015).

The advent of machine learning and artificial intelligence means that is possible to analyse the building performance data as real-time information accumulates and make intelligent decisions about how buildings should react to its microclimate. At this point it is almost as if the building could be considered to be "living", as it systematically adapts to the changes in the microclimate conditions, reports issues and requests resources. In the context of shading applications, for example, issues would be where building overheats, and resources would be the demand for additional air conditioning or artificial lighting. Access to natural daylight is important for a healthy living environment; therefore, it is important the building adapts to keep light within optimum levels and avoids glare. Linking the solar shading to these systems can lead to significant savings (Tzempelikos, 2007). Building performance simulation tools such as the © IES VE enable designers to evaluate and refine their designs. These simulation methods can be applied to the development of dynamic solar shading systems too, but these are limited when it comes to assessing how the façade should react real-time, both from a design and operational perspective. This is where the live data performance monitoring takes over, building on the simulation data, to more intelligently ensures the shading response is appropriate.

Developing a prototype BIM-SDA-SBE application (Ceranic et al., 2018), involved connecting a building information model created in ©Autodesk Revit to the sensors in the real world using © Autodesk Dynamo visual programming language to collect and evaluate real-time sensor data readings, and then programming the intelligent kinetic façade climatic response, either via controlling the façade system apertures or their shading angles.

An Arduino Uno Board has been used to take readings of current room conditions, notably temperature and relative humidity using a DHT22 sensor (see Figure 8.), and light levels (lux) using a TSL2591 sensor (see Figure 8.). Table 8.1 gives specification data and levels of accuracy of the two types of sensors used for this research.

Table 8.1 Physical properties of sensors used (Adafruit, 2018).

Sensor	Reading	Units	Range	Accuracy
DHT 22	Humidity	Relative Humidity	0-100%	2-5%
	Temperature	Degrees Celsius	-40°C - 80°C	±0.5°C
TSL 2591	Illuminance	Lux	0 - 88,000 Lux	188 uLux

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Figure 8.2. DHT22 sensor wiring layout for real-time temperature and humidity output. (Arduino, 2016).

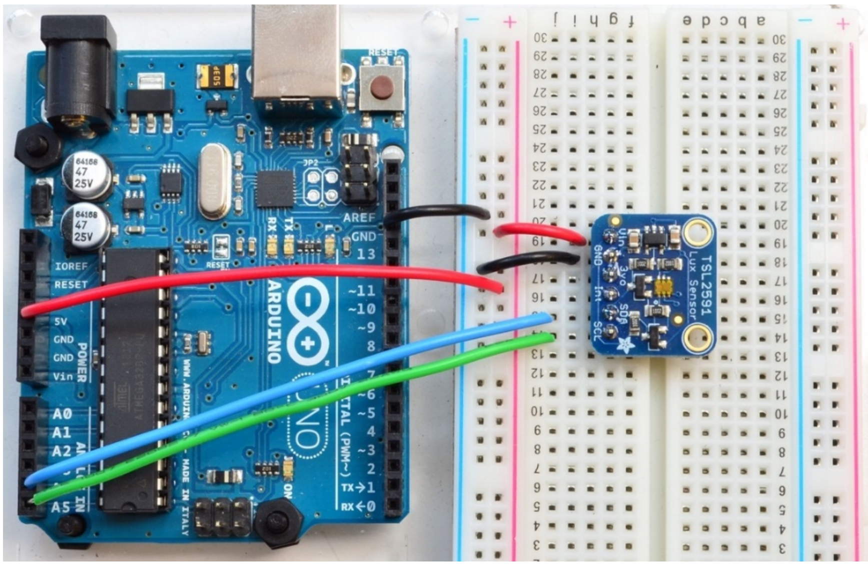


Figure 8.3 Set up of the TSL2591. (Source: Author).

8.2 System Implementation

The Arduino board uses the programming language C++ which doesn't natively communicate with BIM tools, such as Dynamo which uses Python. To form the bridge, research has used the Dynamo package called Firefly (Kensek, 2014.), enabling us to bring the data in a useable format. To be able to continually see the latest data in Dynamo, the periodic running function (6000ms) is used, required as the nodes which read the Arduino output need to be refreshed continuously. When working with large Revit models, the number of calculations often puts a strain on computational power. To overcome this the reading of data and determination of shading angle were split into two Dynamo instances running in the parallel. The first instance writes the live condition data to a file (see Figure 8.4 and Figure 8.5), and the second instance uses the link to the Revit model. This mimics the flow of data in typical building management systems where sub-systems perform different linked functions. In reality, changing the façade more frequently than every 30 minutes would likely result in disturbance for the occupants without significant gains in terms of more effective control of heat gains and access to the daylight.

Early evaluation solutions involved applying linear regression to the collected data to predict the future conditions, building a temperature profile for the conditions like those used in the building performance evaluation. The intention with a fully deployed system is to have a simulated temperature profile which would then be modified to reflect the condition data being reported by the sensors in the real-time. Developing temperature and reaction profiles for all seasons and conditions enables more informed decisions to be made.

```
/**************************************************************************/
/*
    Configures the gain and integration time for the TSL2561
*/
/**************************************************************************/
void configureSensor(void)
{
  // You can change the gain on the fly, to adapt to brighter/dimmer light situat
  //tsl.setGain(TSL2591_GAIN_LOW);    // 1x gain (bright light)
  tsl.setGain(TSL2591_GAIN_MED);      // 25x gain
  //tsl.setGain(TSL2591_GAIN_HIGH);   // 428x gain

  // Changing the integration time gives you a longer time over which to sense li
  // longer timelines are slower, but are good in very low light situtations!
  tsl.setTiming(TSL2591_INTEGRATIONTIME_100MS);  // shortest integration time (br
  //tsl.setTiming(TSL2591_INTEGRATIONTIME_200MS);
  //tsl.setTiming(TSL2591_INTEGRATIONTIME_300MS);
  //tsl.setTiming(TSL2591_INTEGRATIONTIME_400MS);
  //tsl.setTiming(TSL2591_INTEGRATIONTIME_500MS);
  //tsl.setTiming(TSL2591_INTEGRATIONTIME_600MS);  // longest integration time (c

  /* Display the gain and integration time for reference sake */
  Serial.println("------------------------------------");
  Serial.print  ("Gain:         ");
  tsl2591Gain_t gain = tsl.getGain();
  switch(gain)
  {
    case TSL2591_GAIN_LOW:
      Serial.println("1x (Low)");
      break;
    case TSL2591_GAIN_MED:
      Serial.println("25x (Medium)");
      break;
    case TSL2591_GAIN_HIGH:
      Serial.println("428x (High)");
      break;
    case TSL2591_GAIN_MAX:
      Serial.println("9876x (Max)");
      break;
  }
  Serial.print  ("Timing:       ");
  Serial.print((tsl.getTiming() + 1) * 100, DEC);
  Serial.println(" ms");
  Serial.println("------------------------------------");
  Serial.println("");
}
```

Figure 8.4 Arduino code for setting up the TSL2591 sensor. (Source: Author).

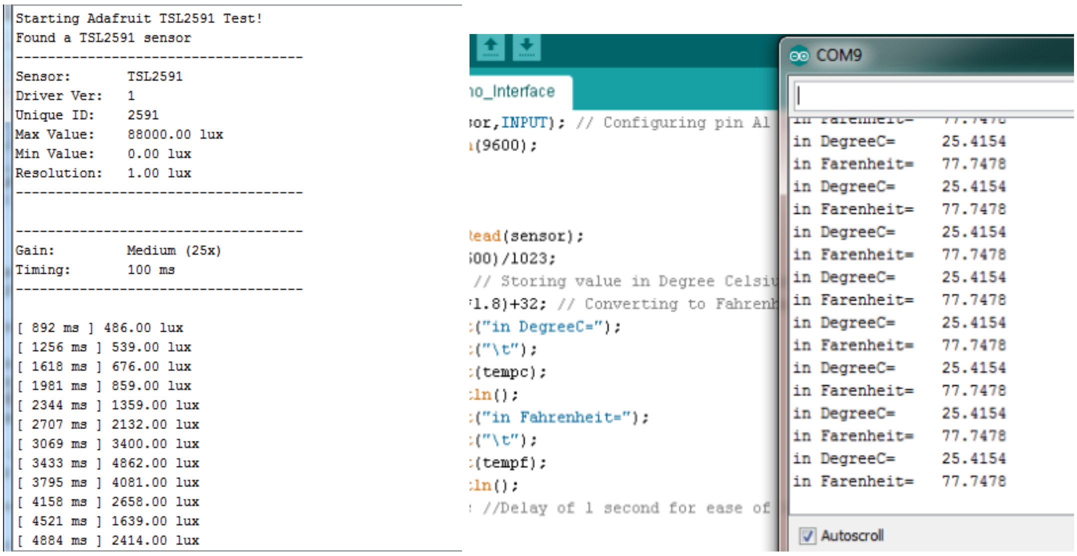


Figure 8.5 Output of ambient light levels and temperature from the two sensors. (Source: Author).

Once the system has ability to read real-time data for light levels, temperature and relative humidity (Figure 8.), the next step was to undertake visual programming in Dynamo to read such data and write them into the parametric calculation process (see Figure 8. and Figure 8.).

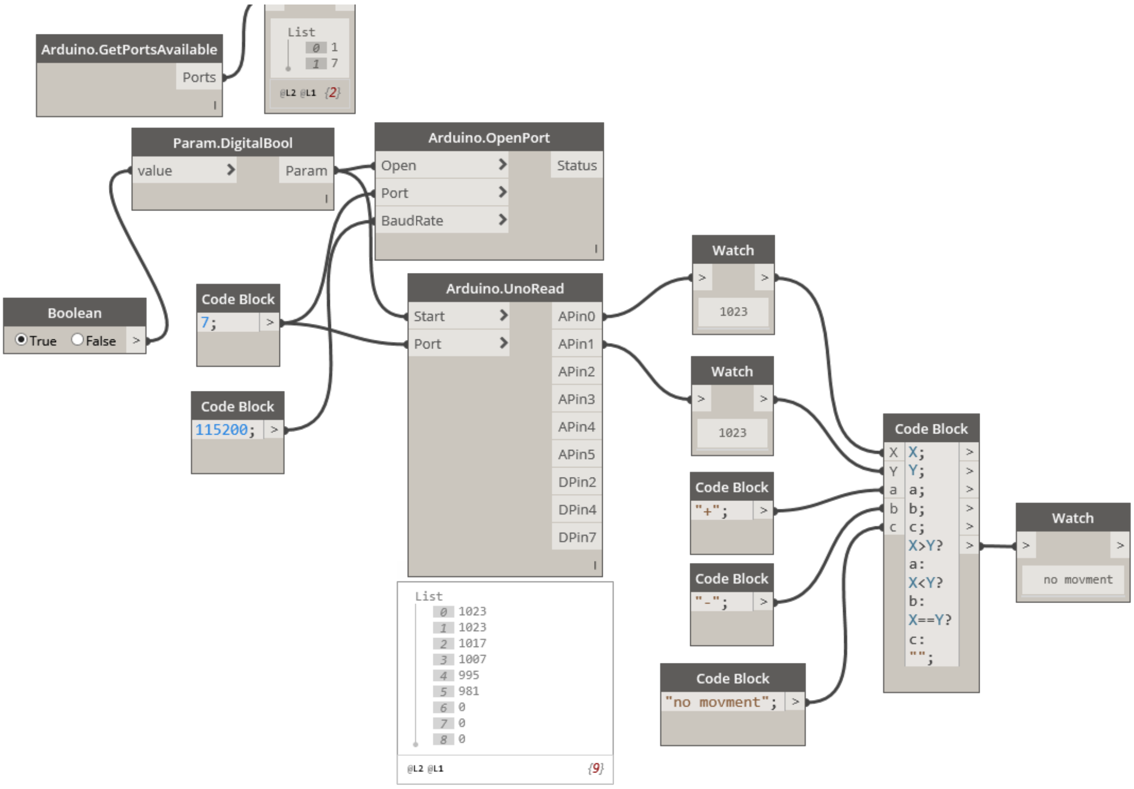


Figure 8.6 Activation of Arduino ports and reading of their data. (Source: Author).

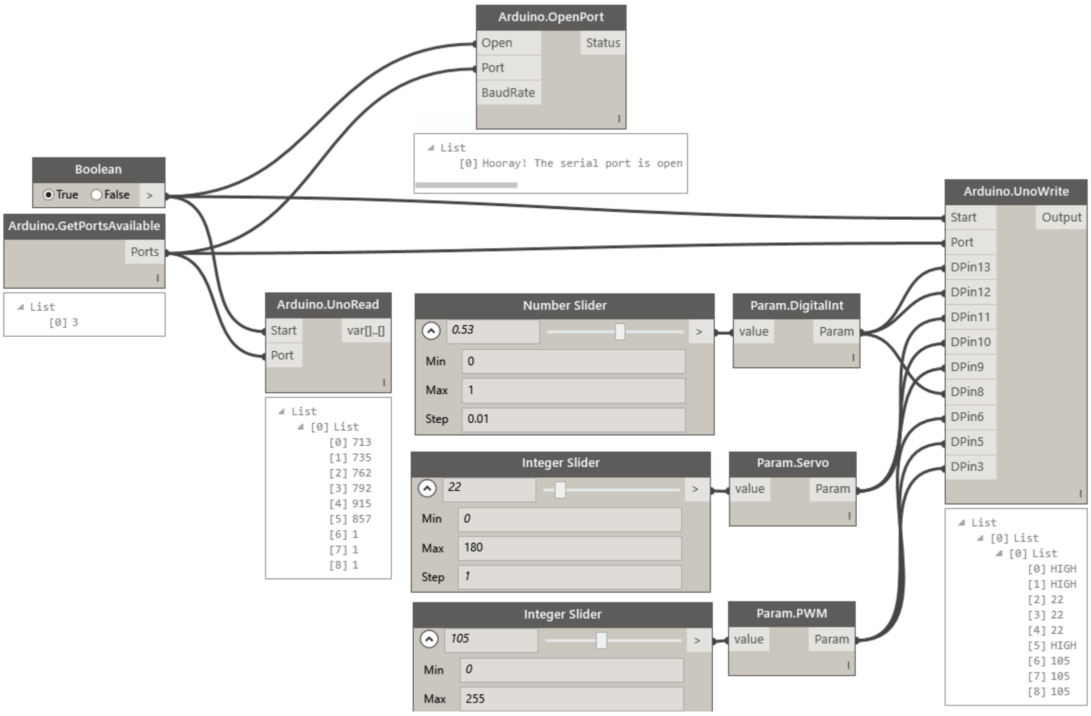
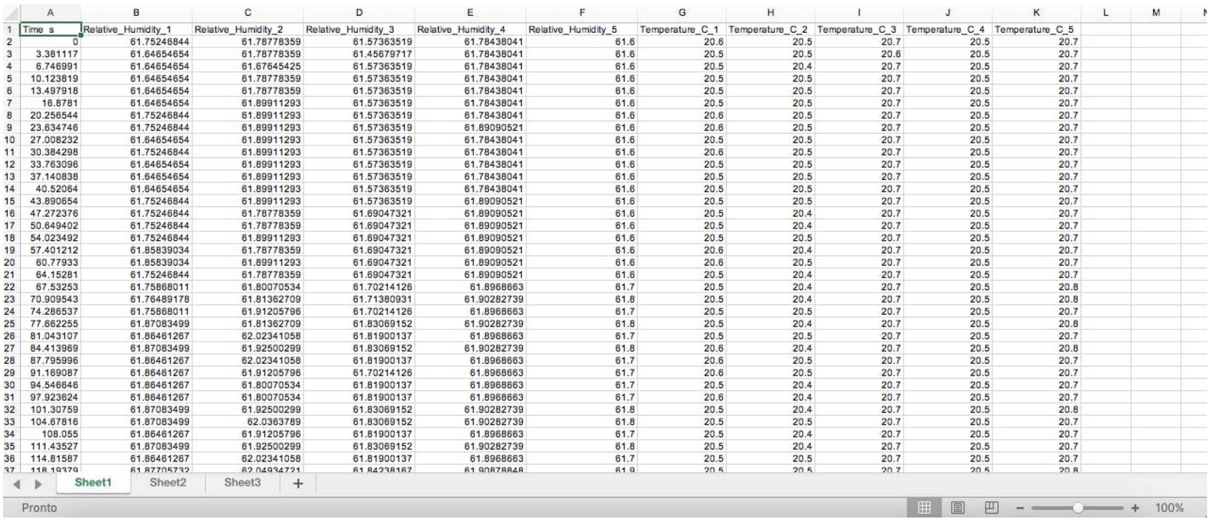


Figure 8.7 Set up for writing data. (Source: Author).



	A	B	C	D	E	F	G	H	I	J	K
1	Time_s	Relative_Humidity_1	Relative_Humidity_2	Relative_Humidity_3	Relative_Humidity_4	Relative_Humidity_5	Temperature_C_1	Temperature_C_2	Temperature_C_3	Temperature_C_4	Temperature_C_5
2	0	61.75246844	61.78778359	61.57363519	61.78438041	61.6	20.6	20.5	20.7	20.5	20.7
3	3.381117	61.64654654	61.78778359	61.45679717	61.78438041	61.6	20.5	20.5	20.6	20.5	20.7
4	6.746991	61.64654654	61.67645425	61.57363519	61.78438041	61.6	20.5	20.4	20.7	20.5	20.7
5	10.123819	61.64654654	61.78778359	61.57363519	61.78438041	61.6	20.5	20.5	20.7	20.5	20.7
6	13.497918	61.64654654	61.78778359	61.57363519	61.78438041	61.6	20.5	20.5	20.7	20.5	20.7
7	16.8781	61.64654654	61.89911293	61.57363519	61.78438041	61.6	20.5	20.5	20.7	20.5	20.7
8	20.256544	61.75246844	61.89911293	61.57363519	61.78438041	61.6	20.6	20.5	20.7	20.5	20.7
9	23.634746	61.75246844	61.89911293	61.57363519	61.89090521	61.6	20.6	20.5	20.7	20.5	20.7
10	27.008232	61.64654654	61.89911293	61.57363519	61.78438041	61.6	20.5	20.5	20.7	20.5	20.7
11	30.384298	61.75246844	61.89911293	61.57363519	61.78438041	61.6	20.6	20.5	20.7	20.5	20.7
12	33.763096	61.64654654	61.89911293	61.57363519	61.78438041	61.6	20.5	20.5	20.7	20.5	20.7
13	37.140838	61.64654654	61.89911293	61.57363519	61.78438041	61.6	20.5	20.5	20.7	20.5	20.7
14	40.52064	61.64654654	61.89911293	61.57363519	61.78438041	61.6	20.5	20.5	20.7	20.5	20.7
15	43.890654	61.75246844	61.89911293	61.57363519	61.89090521	61.6	20.5	20.5	20.7	20.5	20.7
16	47.272376	61.75246844	61.78778359	61.69047321	61.89090521	61.6	20.5	20.4	20.7	20.5	20.7
17	50.649402	61.75246844	61.78778359	61.69047321	61.89090521	61.6	20.5	20.4	20.7	20.5	20.7
18	54.023492	61.75246844	61.89911293	61.69047321	61.89090521	61.6	20.5	20.5	20.7	20.5	20.7
19	57.401212	61.85839034	61.78778359	61.69047321	61.89090521	61.6	20.6	20.4	20.7	20.5	20.7
20	60.77933	61.85839034	61.89911293	61.69047321	61.89090521	61.6	20.6	20.5	20.7	20.5	20.7
21	64.15281	61.75246844	61.78778359	61.69047321	61.89090521	61.6	20.5	20.4	20.7	20.5	20.7
22	67.53253	61.75868011	61.80070534	61.70214126	61.8968663	61.7	20.5	20.4	20.7	20.5	20.8
23	70.909543	61.76489178	61.81362709	61.71380931	61.90282739	61.8	20.5	20.4	20.7	20.5	20.8
24	74.286537	61.75868011	61.91205796	61.70214126	61.8968663	61.7	20.5	20.5	20.7	20.5	20.7
25	77.662255	61.87083499	61.81362709	61.83069152	61.90282739	61.8	20.5	20.4	20.7	20.5	20.8
26	81.043107	61.86461267	62.02341058	61.81900137	61.8968663	61.7	20.5	20.5	20.7	20.5	20.7
27	84.413969	61.87083499	61.92500299	61.83069152	61.90282739	61.8	20.6	20.4	20.7	20.5	20.8
28	87.795996	61.86461267	62.02341058	61.81900137	61.8968663	61.7	20.6	20.5	20.7	20.5	20.7
29	91.169087	61.86461267	61.91205796	61.70214126	61.8968663	61.7	20.6	20.5	20.7	20.5	20.7
30	94.546646	61.86461267	61.80070534	61.81900137	61.8968663	61.7	20.5	20.4	20.7	20.5	20.7
31	97.923624	61.86461267	61.80070534	61.81900137	61.8968663	61.7	20.6	20.4	20.7	20.5	20.7
32	101.30759	61.87083499	61.92500299	61.83069152	61.90282739	61.8	20.5	20.4	20.7	20.5	20.8
33	104.67816	61.87083499	62.0363789	61.83069152	61.90282739	61.8	20.5	20.5	20.7	20.5	20.7
34	108.055	61.86461267	61.91205796	61.81900137	61.8968663	61.7	20.5	20.4	20.7	20.5	20.7
35	111.43527	61.87083499	61.92500299	61.83069152	61.90282739	61.8	20.5	20.4	20.7	20.5	20.7
36	114.81587	61.86461267	62.02341058	61.81900137	61.8968663	61.7	20.5	20.5	20.7	20.5	20.7
37	118.19379	61.87705732	62.04934721	61.84238167	61.90878848	61.9	20.5	20.5	20.7	20.5	20.8

Figure 8.3 Real-time data from sensors stored in spreadsheets. (Source: Author).

For the purposes of this test solution a core list of parameters (Table 8.2) were established, the value of which was populated in the model and related directly to the proposed shading solution. Another advantage of hosting all data within a data model is that it enables multiple systems to use the same data.

Table 8.2 Solution Information Parameters per data source, ones in Bold are used (Callaghan, 2018).

Model	Space	Windows	Sensor
Location	Level	Thermal Resistance	**Temperature**
Longitude	**Volume**	**Total Window Area** (sum of Window Areas)	**Relative Humidity**
Latitude	**Air Density**	**Solar Heat Gain Coefficient**	**Lux**
Elevation (or Altitude)	**Air Mass** (Density*Volume)	Visual Light Transmittance	
	Room Function	**Heat Transfer Coefficient**	
	Max Lux Level	**Window Area**	
	Min Lux Level		
	Comfort Temperature		
	Comfort Tolerance		
	Number of Occupants		
	Occupant Gains		
	Equipment Gains		

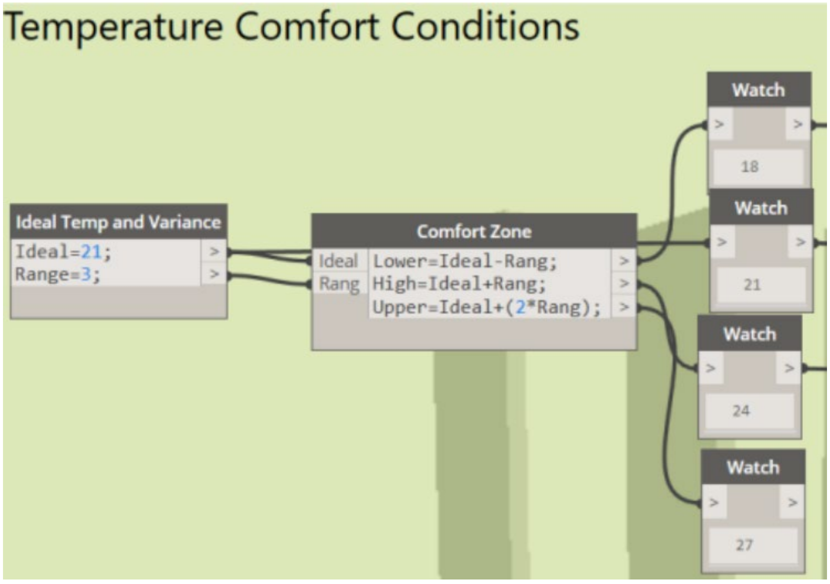


Figure 8.4. Dynamo graph group for assessing the temperature comfort conditions (NGUYEN et al., 2018).

Temperature results are evaluated against the defined comfort conditions (see Figure 8.4). Depending on real-time sensors readings in relation to 21ºC +/-3ºC adopted thermal template and 300-500 required lux level conditions for this case, the opening angles of the façade shading panels are adjusted. As part of the linear regression approach, data was cumulatively evaluated in 30-minute groupings to determine the likely temperature and light values 30 minutes later. Changing the façade shading panels angle more frequently than every 30 minutes would likely result in disturbance for the occupants without major gains in terms of more effective control of heat gains and access to the daylight. Determining the correct aperture of the solar shading device needs to rely not only on the indoor comfort data analysis but also the external climate data simulation. For example, incorporating Weather, Sun Position and Room Characteristics enables adaptable solutions which react to not only what is typical or predicted, but the actual conditions. This is achieved by linking data and geometry from a building information model in real-time (see Figure 8.5).

Solar Analysis was carried out with nodes for getting the local weather data and the position of the sun relative to the position of the building being visually programmed in (see Figure 8.5). The sun Azimuth and Altitude are carried forward to the solar control nodes as these give the relative position in relation to the elevation. Relating the Sun Path to the location and orientation of the facade allows the shading angle of the panels to be optimised for each shading array, enabling a curved or multifaceted façade system to be evaluated more appropriately.

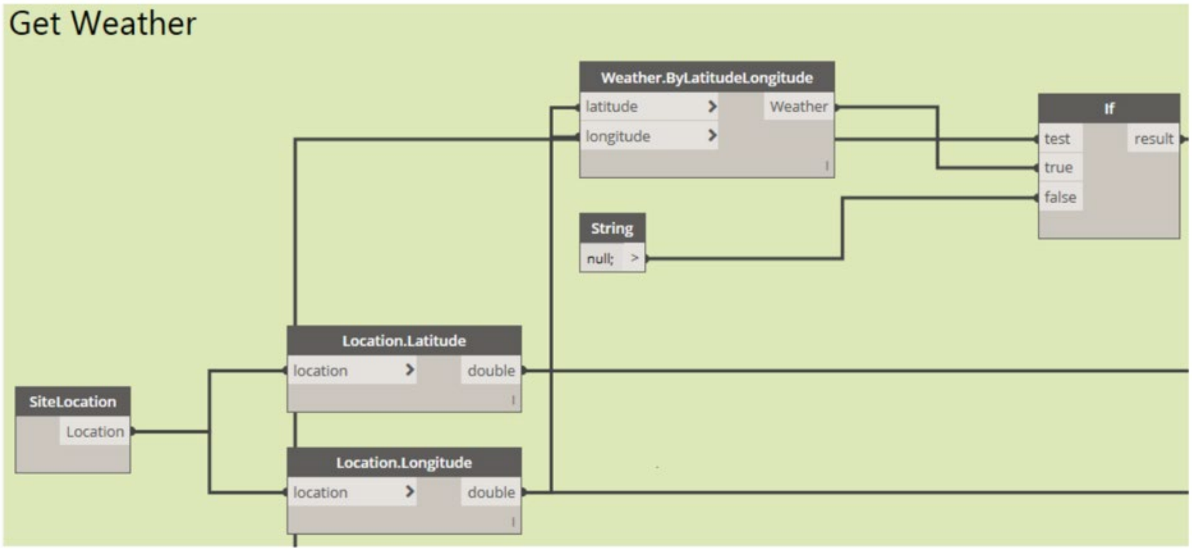


Figure 8.5. Dynamo Graph for getting weather data at a model location (NGUYEN et al., 2018).

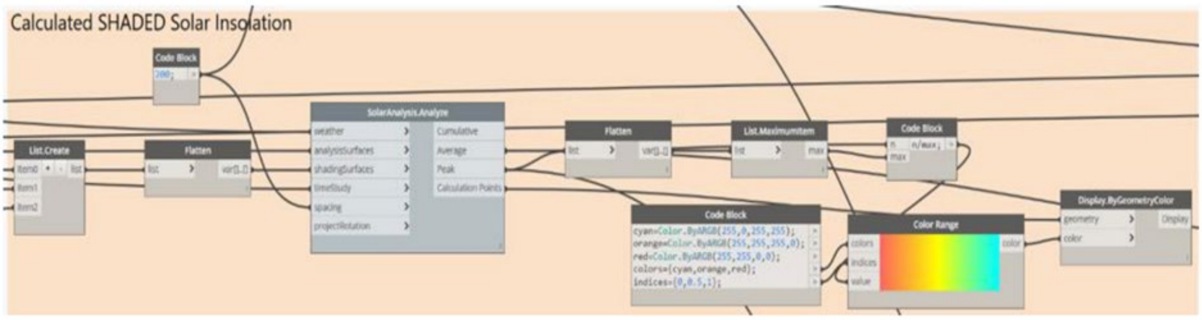


Figure 8.6. Dynamo Group with calculated data directed to a coloured grid (NGUYEN et al., 2018).

Using the package ‘Solar Analysis’ for Dynamo, it was possible to determine the values of solar insolation (see Figure 8.6). Calculations are run in parallel for when the openings to a room are unshaded, and when the shading at the determined angle is included. Simulated energy levels can be displayed in a coloured grid pattern giving the designer an understanding of where the shading is being more productive. Calculating Net Solar Gain, in both shaded and unshaded conditions, gives the heat gains input difference which depending on whether it is positive or negative, will provide the heating or cooling scenario. Recording these values enables adjustment in the calculation to optimise the required temperature reduction.

8.3 Results

Figure 8.7 shows the shading angle data plotted against the temperature. In the linear regression scenario, the temperature was the main parameter with the light levels adjusting the shading angle accordingly. However, compared to the temperature, there is less of a colouration, which could be partly explained by the temperature control factor introduced for temperatures above the upper limit of the comfort zone of 23ºC. From 0 to 110 minutes the temperature was above 23ºC, which resulted in an extra 10% added by the temperature control factor to the turning angle of shading device to decrease the solar radiation and thus prevent overheating more rapidly.

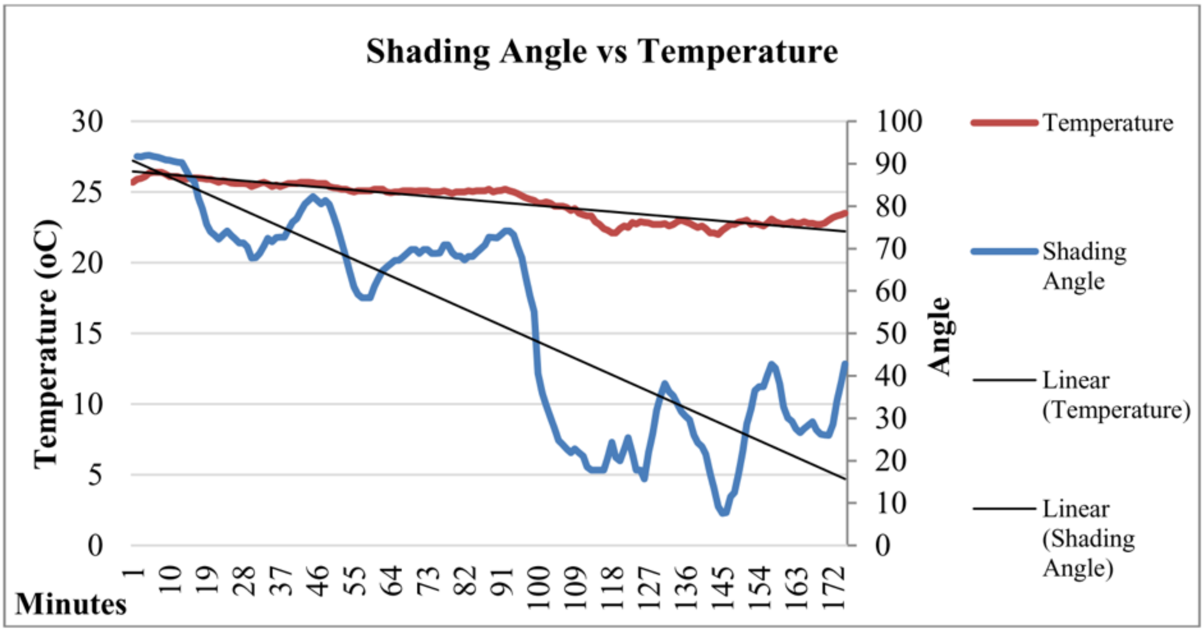


Figure 8.7. Graph showing the shading angle in relation to temperature, including a linear trend.

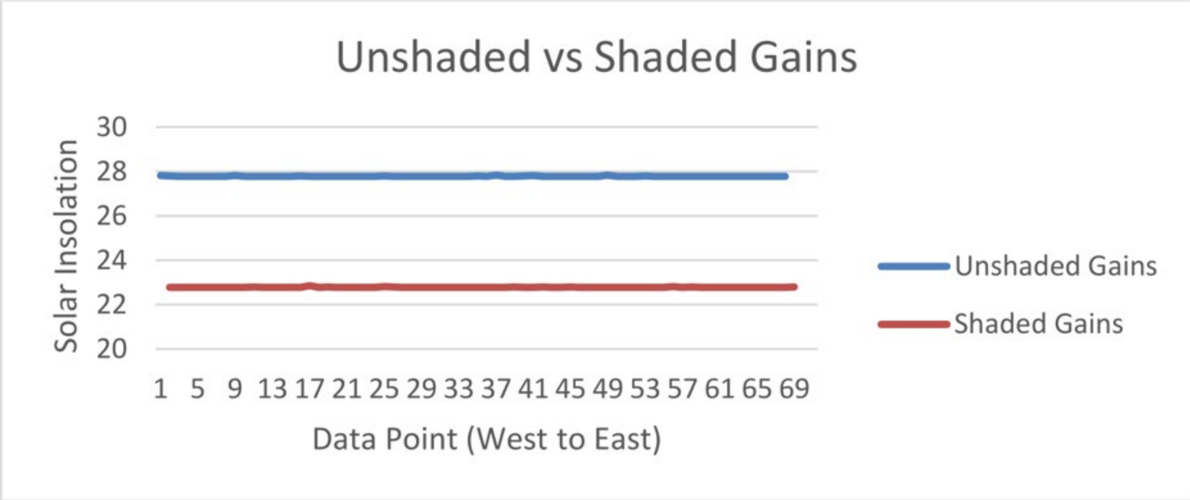


Figure 8.8. Graph comparing Solar Insolation in Simulated Shaded and Unshaded Conditions.

Figure 8.8 below shows the effectiveness of the shading by comparing shaded and unshaded solutions involving sun, weather and location information. When considered in the context of the other heat sources in a room, reducing the overall solar gains can significantly contribute to a reduction in overall temperature. In hotter climates where mechanical cooling systems are often employed, this should significantly reduce the cooling load required.

8.4 Conclusions

The developed prototype model adapts in real-time via operating upon communication and data-regulation protocols for sensing and processing building performance information, based on the integration of shape grammar, building information modelling (BIM) and system optimisation. The method for integration of building performance simulation with the building energy management system (BS-BMS) into smart building environments (SBE) based on the open-source, has been presented and also been considered, and a prototype structure for their amalgamation has been established. As reported in the research, the 'proof of concept' for the sensor-actuator control has already been developed via BIM-based visual programming, and virtual sensors with IFC shared parameters, distinctively defining a sensor model and type. Thus, virtual objects, in this case, kinetic facades systems, are able to self-actuate and regulate light levels and solar heat gains of the actual building component, via its real-time sensor-actuator connection. This is based on the results of visual programming algorithms that use information from a "virtual to real" sensor data within the BIM environment.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary

This final chapter evaluates the methodology used to achieve research objectives, summarises the findings, reviews the contribution of the theoretical study, recognises its limitations, and finally recommends opportunities for future research work.

The research first reviewed the traditional Vietnamese patterns in the context of the growing popularity of decorative façade systems in late modernism and the digital age of architecture (see Chapters 1 and 3). Today, the use of cultural patterns and decoration on the façade systems is more frequently encountered compared to the early and mid-20th century. Despite its long history of culture and traditional architecture, a little attempt was made to understand the origins, history and language of vernacular Vietnamese cultural patterns, motifs and ornaments.

Chapter 4 explored in depth published literature in kinetic façade external solar shading systems, critically searching for key concepts by which the modern building facades have been designed to adapt to climatic and external environmental conditions. Also, appropriate methods and strategies were found to accompany the concept of kinetic shading system developed in this research.

Chapter 5 critically analysed and evaluated the main characteristics of shape grammars, instead of reviewing their history and development, which have been described extensively in the literature. It looks at shape grammar origins in Noam Chomsky's theory of linguistics – the syntactic structures, seeking for unexploited theories and concepts for shapes generation in the field of architecture. As such, analytical shape grammar and shape emergence as qualitative approaches were found to be the missing link for developing new generative designs, based on inspiration from traditional Vietnamese geometric patterns.

Unlike other studies concerning shape grammars, which have been aiming to demonstrate their ability to automate the design generation process in computer applications, this research attempted to determine the shape grammars capability to support the principal nature of design - a conceptual journey experienced through a human-led computation. Indeed, Chapter 6 introduced the KiSS, a novel design framework of a kinetic shading system (KiSS) for Vietnamese contemporary façade design. It is a unique mixed method framework based upon concepts of shape emergence, geometric decomposition, grammar-based generative design and multi-objective optimisation. The framework developed a number of shape grammar rules and schemas for a novel Vietnamese pattern use in building façade shading system design, with the intention to inherit and pass Vietnamese cultural presence to the next generation of contemporary building facades designs. Eight façade apertures representing eight shading compositions were generated for the simulation evaluation and validation in Chapter 7.

Chapter 7 demonstrated the sustainable building performance of the KiSS framework. The shading devices were modelled in a BIM-based generative system and then tested in a BIM-integrated simulation (BSM). The tests were conducted involving climates of three Vietnamese cities – Hanoi, Hue and Saigon with a study case of office space facing three orientations – West, South and East. The BSM presented a bottom-up, data-driven framework responsible for making consistent and reliable decisions. Such hierarchical process saw extensive and diverse simulations which were carried out, resulting in a comprehensive set of data which was vital for the optimisation. Finally, optimisation processes helped to rationalise and saturate the dimensionality of the data gained from the simulations. In fact, quantitative methods – Min-max Normalisation and Weighting Factors were used as bi-dimensional reduction analysis to prepare and organise the data for the evaluation.

Consequently, this research has proved that a KiSS framework can lead to an intricate shape organisation for façade shading design, which not only fulfils the aesthetical desires of contemporary interpretation of traditional Vietnamese patterns but also proves the ability of the framework to generate kinetic systems with superior sustainable performance over the whole year.

Chapter 8 reflected upon KiSS framework as the performance of shading device was analysed in a BIM-based physical environment (NGUYEN et al., 2018), via responding to both results of an undertaken simulation and data-regulation protocols responsible for sensing and processing building performance data in real-time. To this extent, a strategy for BIM integrated sustainable design analysis (SDA) has also been deliberated, as a framework for exploring the integration of building management systems (BMS) into smart building environments (SBEs).

Although not strictly in the scope of this research, the proposed system was able to simultaneously react in real-time to lighting levels and temperature, bringing the KiSS's framework a step closer to the notion of truly climate-adaptive building shading systems.

9.2 Research Methodology and Achievement of Objectives

9.2.1 Methodology

The proposed study has dealt with distinct topics under the notion of pluralism and Dewey's philosophy of Pragmatism– the methods of inquiry. John Dewey's philosophy was one of the keystones for scientific exploration of his time. The pragmatist methods of inquiry demand this research for reasoning to assists the emergent ideas, which conversely must be built on analysis and reflection – the way in which Schon (1983) and Stiny (2001) built their theories. Notably, it was the reflection on design activities in their mind, not the reflection in design.

Unlike present theories, which mainly concentrate on the idea of developing a complete design process, Dewey's Pragmatism and Nunamaker's Systems Development philosophy resulted in the return to pluralism and relativism, rather than trying to prove 'eternal truths' with precision. This philosophy enriched and extended aesthetic experiences in this research, allowing the system to engage with diverse objectives and different processes, which have helped the author to focus on particular frameworks of the whole design process, such as shape generation and energy simulations, without fear of 'breaking down' the entire system development.

The researcher was able to see the development as an evolutionary process, to justify and adapt to occurring situations and propose appropriate approaches for resolution of research objectives, whether in design domain or in technical area, analyse the problems, develop a dynamic roadmap to determine the rationality of alternative solutions, based on the proposed efficient methods and techniques and finally evaluate the built system.

9.2.2 Achievement of Research Objectives

Five research objectives were proposed in Chapter 1 to achieve the aim of this study. Table 9.1 provides a summary of methodologies applied to achieve those objectives, together with reference to relevant Chapters.

Table 9.1 Methods used to achieve the research objectives

	Objective	Method(s) of Achievement	Chapter
1	To undertake an in-depth literature review and critically explore current approaches to the sustainable kinetic design of façade shading systems.	-Literature review	1, 4

		-Discussion of research findings	
2	To analyse and critically resolve novel theoretical approaches to adaptive kinetic pattern design in relation to parametric generative design methods in architecture.	-Literature review -System design -Discussion of research findings	1, 5, 6
3	To develop parametric strategies and propose original shape grammar languages for the design of kinetic façade shading systems, inspired by the research into origins and history of traditional patterns, motifs and ornaments in Vietnam.	-System development -System design -Discussion of research findings	3, 6, 9
4	To develop and critically evaluate, via extensive thermodynamic simulations, a novel prototype framework for adaptive and responsive kinetic shading systems.	-System testing and validation -System evaluation -Data analysis -Discussion of research findings	7, 9
5	To formulate a strategy for BIM integrated sustainable design analysis (SDA) and optimisation of kinetic façade shading systems, as a conceptual framework for exploring the integration of building management systems (BMS) into smart building environments (SBEs).	-Literature review -System design -System development	8

9.2.2.1 Original Shape Grammar Languages

The subject of this research was to research, develop and critically evaluate novel parametric generative design tools and strategies for innovative and responsive kinetic facade shading system (KiSS), aimed at contemporary office design in Vietnam.

The system development was based upon theoretical research and implemented using generative design approaches, based on the conjectural constructs of shape grammar concepts, investigations in traditional Vietnamese patterns, building simulation, system optimisation and building information modelling (BIM) integration.

Key findings from the KiSS framework development established in Chapter 6, were:

- Based upon notions of shape grammars, shape emergence and geometric decomposition, the framework incorporates analytical and generative shape grammars (ASG and GSG), sustainable design analysis (SDA) and building information modelling (BIM), coupled with visual programming (VP).

- The key concepts, creation of rules and language of shape grammar, patterns variation, and approach to new pattern generation are explained. Based on the recognition and manipulation of generic rules, either by using original rules with different parameterisation or by using original shapes with a different formulation, after an extensive analysis of their vocabulary and the description of transformation and composition rules.
- The design schema is expressed as a combined outcome of creative exploration of Vietnamese patterns, motifs and ornaments using analytical shape grammars, followed by the creation of novel patterns using generative shape grammars, capturing the essence of shape emergence.
- Derived from the evolutionary framework of design thinking, the key concepts and principles of parametric design thinking are introduced, defined and illustrated.
- Critiqued for quality and aesthetics by the designer through a creative interrogation. At this stage, the designer works at a conceptual level, using experiences, knowledge and imagination and establishing the process of transitioning from the paper-based design exploration to computational models of design thinking.
- Able to contain similar spatial structures, share the same shape rules, while unfolding diverse patterns languages and styles, as the author was able to interpret traditional Vietnamese patterns and motifs via multiple shape grammar schema.

9.2.2.2 Parametric Strategies

KiSS's BIM-based generative system was proved to be a comprehensive framework in which the shape creation, composition and generation form the first key part and the BIM integrated visual programming forms the second key part. It is proposed to be used by designers to regulate a workflow for parametric programming of shape grammar geometries and rules in a generative manner, triggering the creation of functional, yet creatively surprising artefacts. The quantitative method offered a tool to visually compute the shape generation process throughout the BIM integrated parametric visual programming.

The achievements of the strategy are:

- The novel aspects of KiSS framework originate from the creation and generation of novel syntactic level models in this research, which deconstruct original Vietnamese patterns, simplify their structure, remove the decorative components and preserve a 'meaning' inherent to the pattern. They are further integrated with BIM using visual programming (VP) methods. Visual programming offers a user-friendly computing environment, making it easier for the research to define the new concept of dynamic shading aperture configurations developed in this study.

- The shading configurations were generated in the form of a dual-layer façade system. Moreover, this concept is unique in the sense that changes of the apertures were calculated as a whole, rather than an arrangement of elemental panels. This approach supported the employment of any types of shapes, for example, line segments or enclosed shapes, desaturating the differences between them. Remarkably, as a result, wide-ranging design options were created from the BIM-based generative system.

9.2.2.3 Evaluation via BIM-integrated Simulation

The results of BIM-integrated simulation methods (BSM) demonstrated that KiSS shading device offered significantly improved performances against previously defined daylighting and energy consumption criteria. The optimised performances were proved to continually meet the illuminance standard in the office space, whilst considerably reducing the energy demand of the space.

The incorporation of parametric design, visual programming and building performance simulation (BPS) within the BIM integrated framework are essential building blocks of the KiSS framework. The evaluation of the system is validated through the comparison of a performance of the unshaded facade, a performance of "best-fixed" façade and performance of a number of configurations of kinetic aperture openings which are adopted in the proposed design (e.g. 20%, 40%, 60%, 80%).

Two quantitative methods were used to combine these validation datasets in an optimisation framework: Min-max Normalisation and Weighting Factors. Three key performance indicators were proposed for the optimisation stage: spatial daylight autonomy (sDA), useful daylight illuminance (UDI) and energy consumption (EC).

In summary, the system development and its frameworks have proved that shape grammar emergence concept can lead to a plentiful amount of kinetic façade shading design possibilities. The proposed kinetic shading devices can have not just a cultural benefit in terms of their approach to vernacular approach to design, but environmental and with its economic benefits too.

9.2.2.4 BIM-integrated Performance Monitoring (BPM)

The 'proof of the concept' process confirmed the ability of real-time data gathering from lighting and temperature physical sensors, successfully imported into the BIM model and represented by BIM families of virtual sensors, which allowed building performance to be monitored and evaluated continuously and in real-time. To this extent, a strategy for BIM integrated sustainable design analysis (SDA) has also been deliberated, as a framework for exploring the integration of building management systems (BMS) into smart building environments (SBEs).

9.3 Research Findings

Key research findings can be summarised as follows:

- Vietnamese traditional patterns are diverse in shapes and rules but often share typical basic layouts, such as square, rectangular and triangular grids. Despite the use of simple initial shapes and grids, traditional Vietnamese patterns have considerably high complexity. When conceived through developed shapes grammars and programmed through parametric design, they can evolve to unexpectedly sophisticated forms, which could be very difficult to comprehend via conventional design means. On these grounds, a new generation of vibrant and diverse patterns can be generated.
- 'Best-fixed' (optimised) apertures are predominantly 40% and 50%, depending on the location and building orientation. Their annual average saving rate is around 10%. The kinetic systems proposed by KiSS can reduce the energy demand even further, by an average of 17% per year. The aperture controls the density of the shading pattern along the facade, which defines the kinetic movements. For example, west-facing offices benefit from the shading density (aperture increase) in the 'down-right' position, whilst the east-facing offices mostly benefit for shading density at the 'upper-left' position. The south-facing offices, for the majority of the year, benefit from the evenly distributed shading density.
- Changes in positions and apertures are two-fold, which was challenging, but, in the end, provided exciting shape emergence and surprising designs. In most of the current solar shading systems designs, changes are one-fold, such as only in the position or only in apertures.

- Impact of orientations on building performance in Hanoi is most evident among the three cities, due to its distinctive four seasons, including a cold winter. The west-facing office scenario sees the highest reduction rate but has the lowest absolute energy-saving value.
- Annually, the highest energy saving can be seen in Hue's west-facing office due to its extreme conditions in temperature and radiation. Saigon achieves peak values of energy-saving overall, particularly on the south side, due to all-year-around high temperatures and solar radiation.
- Heating is needed in Hanoi (from December to March) and partly in Hue (December – January), whilst cooling is demanded for the rest of year and for all year long, especially in Saigon (no heating requirement). As a result, heating loads are much lower than cooling loads, in all locations.
- During cold weather in Vietnam (Hanoi and Hue) cloud cover is prominent. Saigon, on the other hand, has the least cloud cover, annually, requiring minimal artificial lighting usage.
- Climatic features, such as the cloud and the sun, play an essential role in analysing daylighting and energy-saving potential. Climatic weather data is crucial in simulation processes.
- Multi-objective optimisation - the method used in this research could be applied to a broader set of performance indicators, for example, the three existing performance indicators (sDA, UDI and energy consumption) could be enriched by the incorporation of daylight factors and glare indicators.
- Operational profiles must be employed in hourly-based sensitivity simulations for higher accuracy as they make the HVAC system adapt to user-defined requirements and occupancy behaviour. Cumulative studies without specific operational profiles could only be useful for early-stage analysis.
- A compromise between energy reduction and daylight provision can be challenging and must be taken into account when carrying out the optimisation. When optimised, KiSS system reduces average annual daylight levels by only 1%, but the total energy demand is reduced by an estimated 6% average, compared to the 'best-fixed' systems.

9.4 Research Contributions

The proposed system framework represents a unique synthesis between multiple matters in the contemporary design of building façade shading systems. It has been incorporated within a BIM integrated framework for the generative design of climatically adaptive kinetic facade shading systems, developed in this research, highlighting following contributions:

1. Decoding the traditional Vietnamese cultural patterns and creating novel rule-based generative designs, based upon interpretation of decoded patterns and shape grammar emergence.
2. Development of original parametric design strategies used for the creation of adaptive and responsive kinetic systems for Vietnamese contemporary façade shading design validated through simulation and optimisation of daylight levels and building energy performance.
3. Development of a novel conceptual framework for BIM integrated sustainable design analysis (SDA) and optimisation of kinetic façade shading systems, including the integration of building management systems (BMS) into smart building environments (SBEs).

The contribution of this study is therefore in the research of Vietnamese geometric patterns, parametric and kinetic façade systems design, and BIM integrated shape grammars generative design.

The key influences are summarised as follows:

- The systematic analysis and recognition of existing Vietnamese traditional patterns, their appearance and compositional structures. The research helps to promote awareness of Vietnam's cultural spatial heritage, which has been somewhat disappearing in its modern society, whilst at the same time contributing to a more sustainable future for the country. Indeed, some of the patterns have been either destroyed or abandoned and hence difficult to track down through the literature and history. By gathering and recording a number of typical types of patterns and motifs in Vietnamese architecture and culture, the study provides a useful repository, which will enable other scholars to source upon.
- A novel concept of geometric patterns generation has been presented, inspired by traditional Vietnamese patterns. The notion of creative exploration of new instances in a given style of traditional patterns is indeed exciting. To generate novel syntactic level

models in this research, it is necessary to deconstruct original patterns, simplify their structure, remove the decorative components, and preserve a 'meaning' inherent to the pattern. It extends possibilities of the actual style by decomposing its original structure, adding imaginary links that have the same compositional qualities, enabling new ways to see those patterns and opening doors to novel designs. Such design evolution is founded under the detailed understanding of underlying patterns and compositional arrangements. In doing so, devised rules of shape grammar have to be flexible enough to allow unexpected elements of a pattern to emerge.

- One of the most significant contributions of this study is the introduction of a methodological framework to create parametric shapes for a novel pattern generation. In the first phase, analytical shape grammars deconstruct traditional patterns to extract design genes; hence, providing an understanding of how those patterns work. The second phase uses generative shape grammars, discovering shape emergence through a creative exploration of novel patterns arising from these genes. The parametric methods contribute with reference to the necessities of novel pattern design – conservative and innovative. The conservative aspect minimises the changes in spatial relations between patterns elements to maintain their origin aesthetics. The innovative one maximises the possible changes of parameters to generate a large number of design options. Importantly, the framework allows creative thinking to emerge during the process.

- The above is encompassed within the KiSS system development as ultimately the most important contribution of this research. It represents the macro framework serving workflows such as BGS (BIM-based generative system) and BSM (BIM integrated simulation methods). The workflows embody data-driven procedures, from parametric shape transformation, information modelling to simulation and optimisation. BGS supports kinetic movements and façade apertures, as they together define the facade variations. When implemented, it will help architects and designers to save time and create more intelligent performance-driven solutions, without a detriment to their creative expression.

- A simplified multi-objective optimisation based on Min-max Normalisation and Weighting Factor analysis was developed in KiSS. It proposes a new approach that can be integrated into visual programming. Such methods can help architects and designers with difficulties that make traditional simulation and optimisation impracticable. It is also a compelling reminder for designers to clarify what needs to be optimised and for what purposes, resulting in deeper insights into their design problems.

- A new concept of kinetic shading façade system was introduced – an 'adapt-by-move' dual-layer system. The shading system operates in a way that increases and decreases its apertures based on the simulation results. In this system, the first layer is 'fixed' to maintain the aesthetic appearance inspired by traditional Vietnamese patterns; the second layer moves to control façade aperture and to help shade at correct positions and at the right time, through the response from datasets analysis obtained from simulation. Indeed, patterns modules are controlled to create both the shading positions and apertures; this is where the system's uniqueness is. In literature, the application of shape grammars to such concept of kinetic shading façade system is distinctive.

9.5 Applicability of the Research Framework

Despite the fact that the research methodology was developed and tested for particular locations, in defined Vietnamese cultural and climatic context, and in its certain urban areas, the methodology is applicable for other parts of Vietnam and generally South-East Asian countries with similar climate. For example, further north mountainous regions with colder weather and highland terrains and river-deltas in the South, in which different climatic conditions and distinctive geometric patterns can be developed. Vietnam has 53 states, including 64 ethnic groups, which make it extremely rich in terms of geographic and culture. Besides, not only office space, other types of facilities in Vietnam such as hospitals, hotels, museums and schools can also benefit from this study, with the external facades that could become a part of their City's cultural metaphor.

South-East Asian countries like Malaysia and Thailand, which share a similar cultural origin with Vietnam, can exploit the proposed KiSS framework and its approach, rather than imitate Western building designs. Therefore, architecture practices will be able to consider surrounding locality and accordingly reflect national and regional cultural identity in a modern way.

For researchers and practitioners, the research supports the fundamental identity of their countries and cities in a new way. Architects will find it easier to apply shape grammars in their design to creatively explore vernacularly inspired and identifiable patterns which will lead to well-performing shading systems designs.

By linking systematic methods with simulation datasets, and accurately transferring them to the generative designs, it will help designers make better decisions. Also, real-world performance monitoring provides large datasets which are hard to analyse and visualise. The KiSS system development provides a comprehensive way to handle such amount of data through BIM-based design and BIM integrated simulations, contributing to the future of real-time climatic adaptive facades for Vietnam.

The KiSS framework manages the optimisation in a flexible manner so that it can be integrated with other normalising techniques at different scales, thus can further improve the efficiency and accuracy of KiSS. Forthcoming studies, in the context of Big Data or Internet of Things, can be developed from this research to investigate an enlarged set of performance indicators, including advanced aspects of thermal and visual comfort.

9.6 Limitations of this Research

Whilst this study has achieved its aim, it has got several inevitable limitations, many of which are related to software and programming capability. One of the main software used in this research, the visual programming tool, namely Autodesk's Dynamo, is a stand-alone programming environment that allows parametric conceptual design exploration. Its functionality and speed are under constant redevelopment. Currently, its built-in library of codes that allow to manipulate geometries and patterns still works at a relatively slow speed. Correspondingly, the KiSS system could benefit significantly when the connection between visual programming, energy modelling and performance simulation tool (IES-VE in this research) is supported better, in which case, such collaboration will offer a smoother workflow of data exchange for the KiSS system. This could be achieved with Python, a high-level programming language that allows users to access the Revit API from Dynamo (application programming interface) in a whole new way. This, however, is considered to be outside of the scope of this research study.

However, these limitations did not affect the quality of the produced work; rather, they are seen as opportunities for future research. The key limitation observed in this research could be solved by technology advancements. What has not been done or could not be done at this time it is likely to be done in the future, with software and hardware advancements. Design tools are getting increasingly sophisticated and artificially intelligent, and some argue that in the future computers could gradually replace architects and designers. This research makes no attempt of that kind, if anything it evolves and elevates the role of architects and designers in a position they deserve, bringing back the imagined through a combination of human creativity and computational design. The architectural theory, since the *Vitruvius* and *De architectura*, and arguably even before, has often debated that design should be parametric and rule-based, but also that design is not done by a simple application of parametric tools but through creative development of its own parametric design methods. In doing so, it is the ideology and philosophy of reflective creativity by Dewey and Nunamaker that will help this progress and will help in the future, as man and machine come together in a symbiotic convergence. Most importantly, it is also the motivation of protecting national cultural significance that helps this research contribute to its author's profession and country because traditions and cultural diversity have always been a foundation of any society, their way of life, and ultimately, their national identity.

9.7 Recommendations for Future Research

Numerous areas of the research merit prospect for further study:

- Types of shape grammar schema and choice of initial shapes: despite Vietnamese patterns typically being consisted of square, triangular or rectangular shapes, more complex types of geometries such as rhombuses, hexagons and octagons could be explored directly within the proposed design framework. Their shape grammar language may highlight additional inspiring aspects of Vietnamese geometric patterns and motifs, revealing more surprises in their aesthetic experience and contemporary interpretations.

- The number of shading positions and orientations: The framework was built to conduct comparative analyses between pre-defined shading apertures in three orientations and five positions, which were practical for the scope of the research. Nonetheless, exploring a wider range of both orientation and positions would help reach more comprehensive datasets for optimisation. Additional shading density compositions and other orientations such as south-east and south-west should be further investigated.

- Performance indicators: The science of daylighting valuation embraces a number of indicators, including Spatial daylight autonomy (sDA), Useful daylight illuminance (UDI), Annual sunlight exposure (ASE), Daylight factor (DF) and Daylight glare index (DGI). Due to computing restrictions, only sDA and UDI were proposed to be used as they were deemed by the research as the most descriptive factors. Future work could expand by using all indicators, and their analysis, in which case a powerful hardware resource would be required. Furthermore, dynamic thermal simulations would be more accurate when natural ventilation and wind directions are also included, taking computational fluid dynamic (CFD) into consideration.

- The lack of interior objects: Most of the simulation studies exclude furniture such as tables and chairs, due to much longer calculating times. However, as unavoidable parts of the indoor environment, they do make an impact on real-world, especially on lighting levels in the rooms. Thus, including furniture in the simulation models will inevitably produce more realistic results.

- The simulation engine employs the standard metrological data, the most popular type used. In order to reach a higher level of climate adaptability in future research, the cloud-based real-time weather data should be integrated. However, the availability and cost of this type of weather data must be taken into account.

- Consequently, real-time monitoring data from the built environment could be integrated within BIM models through a network of physical-virtual sensors connections, empowering KiSS to maximise occupant comfort and minimise energy demands based on the real-time environmental feedback. Other methods, such as BIM-based data mining could be appropriate for further KiSS framework improvement.

- The solar shading of roof lights, skylights, windows and roof glazing systems such as saw-tooth roof could be integrated with further research, given that they are greatly exposed to the sun, due to high solar altitudes in Vietnam.

- Building the (prototype) physical model of the system: in order to complete the Nunamaker’s system development, constructing a prototype system based on the KiSS parametric models could be developed in future research. The model and its performance monitoring may reveal any simulation shortcomings, as well as constructional difficulties in the proposed shading design installation, and eventually result in an improved solution for shading systems being constructed in reality.

- Other, more potent multi-objective optimisation methods, together with their Pareto optimal solution spaces, could be explored in future research. In such a way, more improved nondominated solutions (solutions which cannot be further improved without negative impact on at least one other objective) could be found.

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Appendix A. Adaptive Shading Devices Literature Review

An expansion of the part of Literature Review in this thesis aims to dig deeper into the fields of Adaptive Facades, Kinetic Shading Devices and Shape Grammars, using quantitative approach, including statistical and visualising methods borrowed from the field of Bibliometrics and Scientometrics. Specifically, Bibliometrics is used to measure impacts of articles, books and authors. Bibliometric methods are commonly employed in the field Information Science. Scientometrics is a sub-field of Bibliometrics that focus on assessment of scientific journals and research articles. This research examined thousands of research paper by analysing their metrics data such as citation metrics extracted from Web of Science and Scopus – the two most respected database in science.

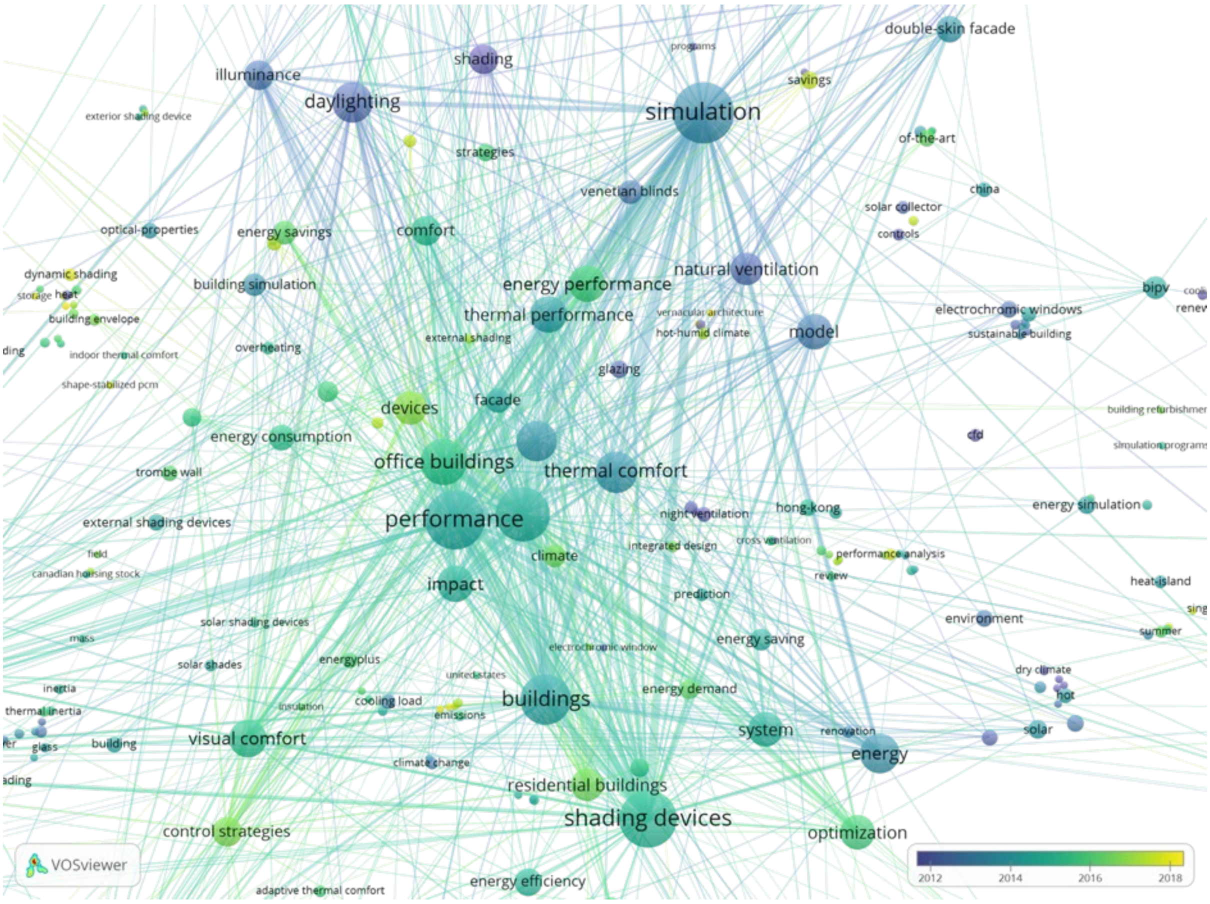

Figure 10.1 Co-occurrence network of keywords in the field of Shading Devices, with colour pallet in regard to the period from 2012 to 2018. (Source: Author).

Although these methods and techniques are mixed-methods and flexible in the same way in which this research conducted its objectives, the topics of Bibliometrics and Scientometrics are not included in the scope of this thesis, hence, output from the expansion are stored in the

Appendices: Appendix A for Shading devices and Appendix B for Shape Grammars. By observing the patterns of occurrences of the keywords and terms, this expansion does add extra depth for the author's understanding of the fields. Key trends, discovery of 'new comers' or emergent terms and new attention of researchers to the fields can also be detected.

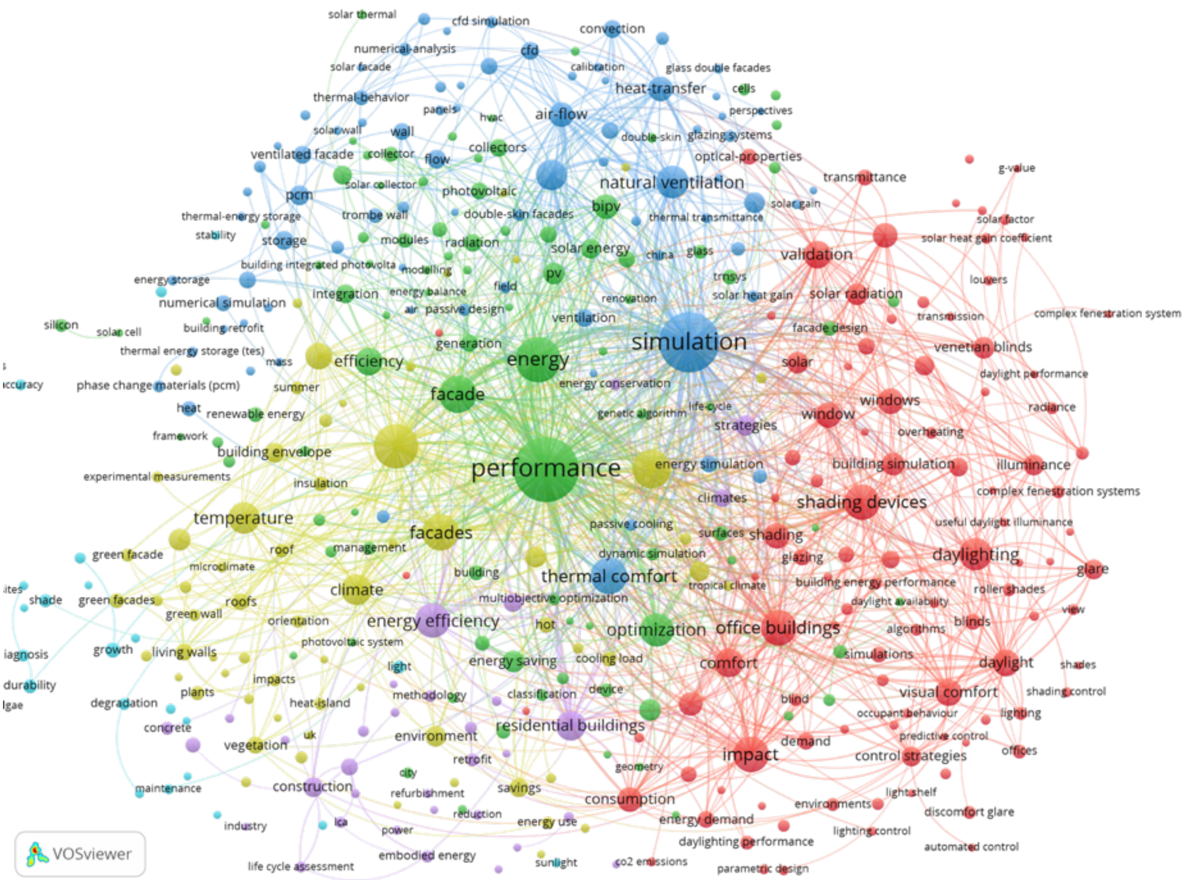

Figure 10.2. Combination of two terms Building Facades Systems and Shading Devices. Terms are groups in clustered with distinct colours. (Source: Author).

As shown in Figure 10.3 and Figure 10.4, Performance, Simulation, Daylighting, Office Buildings and Energy Performance are the terms that occur most frequently and also have strongest connections with other terms. Visual Comfort, Energy Efficiency, Thermal Comfort and Natural Ventilation are not far behind, and are potentially becoming the most influential research topics.

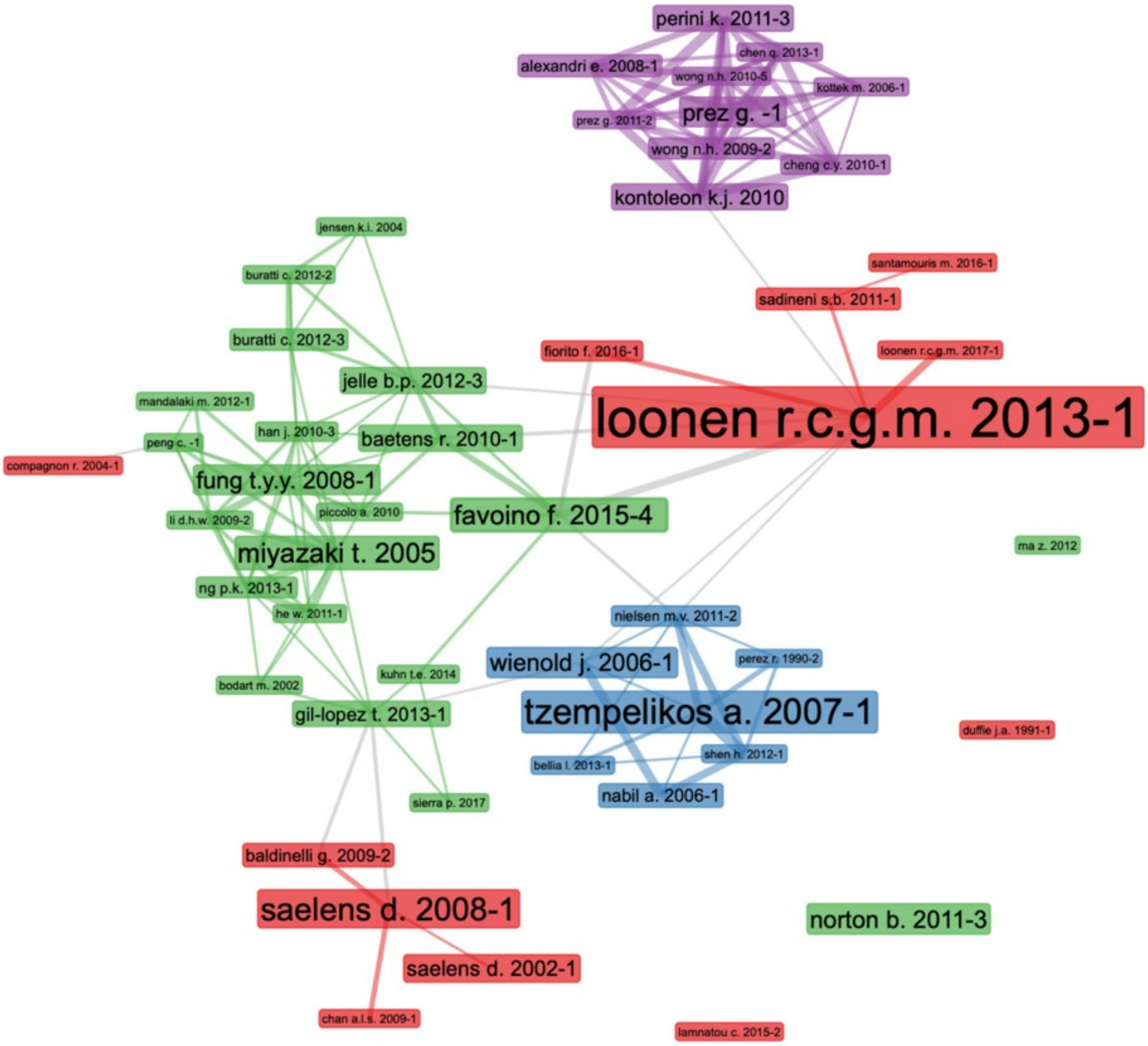

Figure 10.5. Network of documents citing connections. (Source: Author).

The works of Loonen (2013), Tzempelikos (2007) and Saelens (2008) are determined in Figure 10.6 as the most linked papers due to their high number of connections. This suggests relevance of specific groups of papers as well as authors. Loonen has the highest number of citations and his group is the biggest (red) but has much less total links compared to others which are in green, blue and purple.

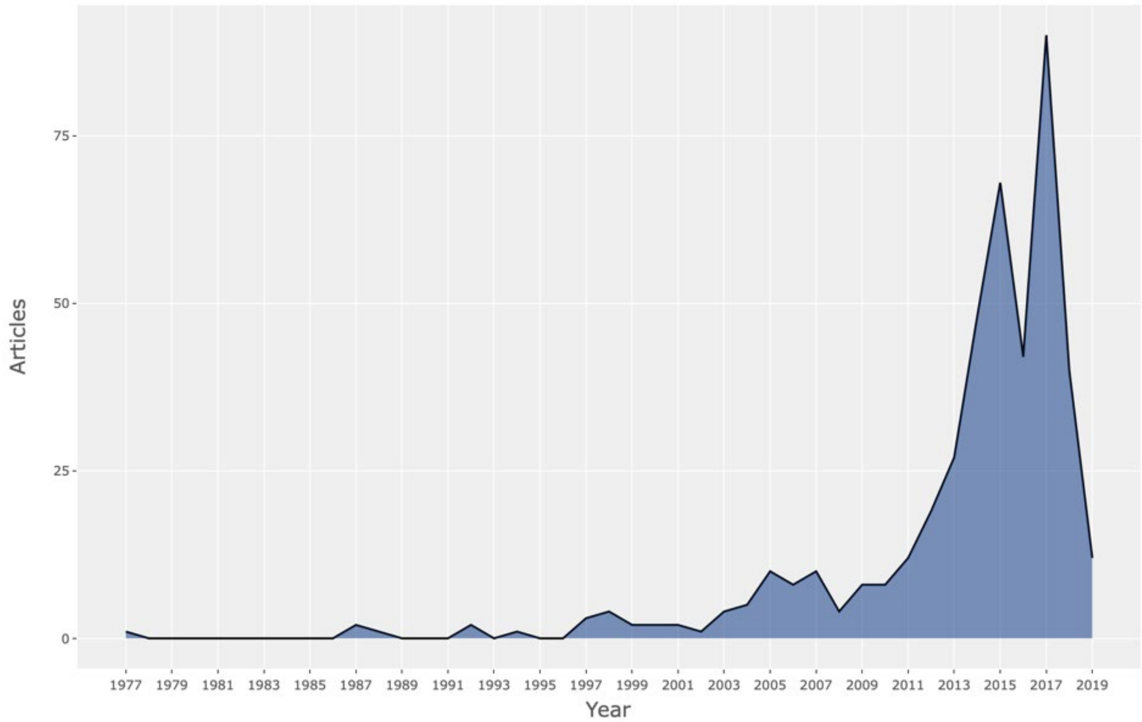

Figure 10.7. Annual scientific production in the field of Building Facades Systems from 1977 to 2019. (Source: Author).

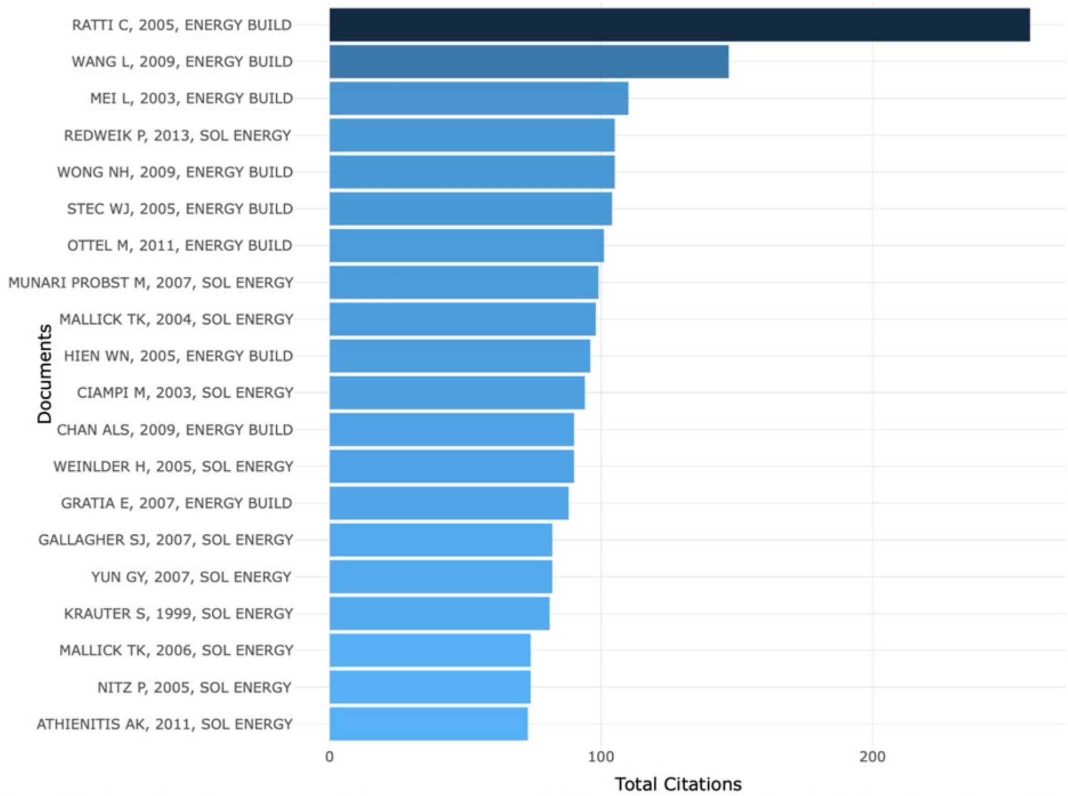

Figure 10.8. Most cited documents. (Source: Author).

Papers of Ratti (2005), Wang (2009) and Mei (2003) obviously are the ‘must read’ papers. This suggests researcher to find the most solid grounds available in the field.

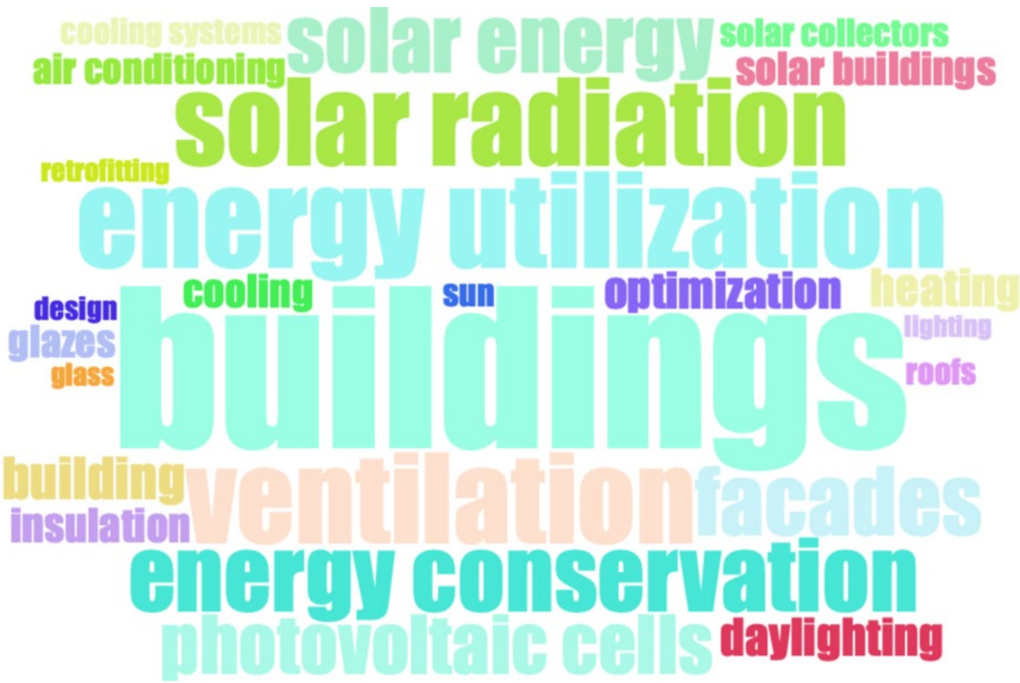

Figure 10.9. Most relevant author's keywords. (Source: Author).

Figure 10.10. Most relevant Keywords Plus. (Source: Author).

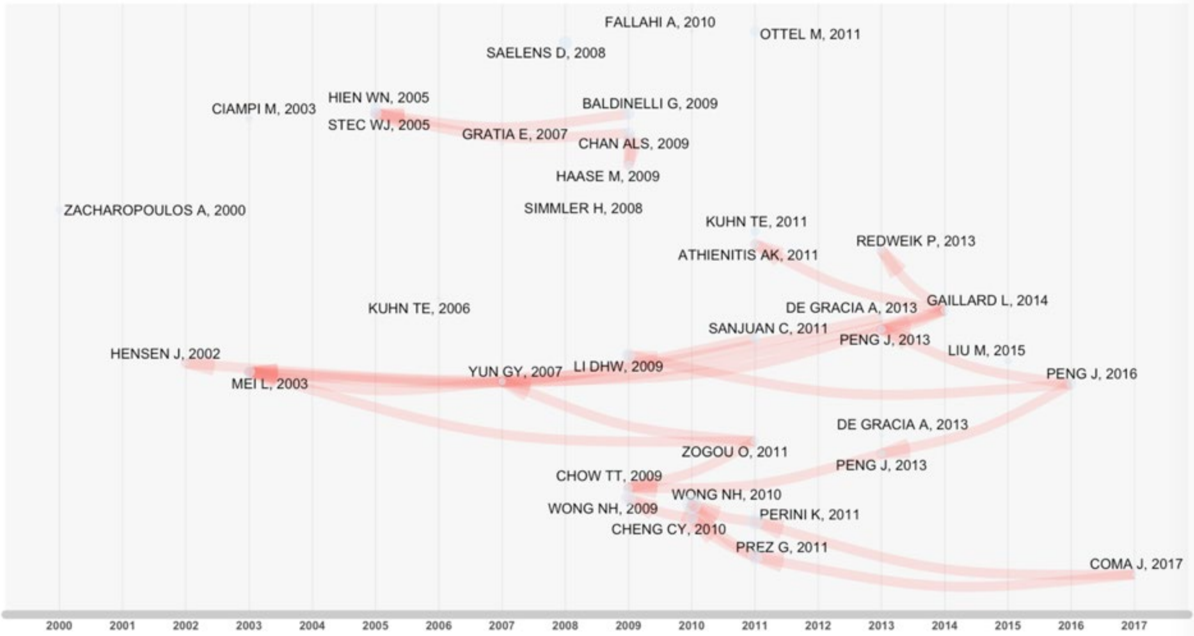

Figure 10.11. Historical direct citation network. (Source: Author).

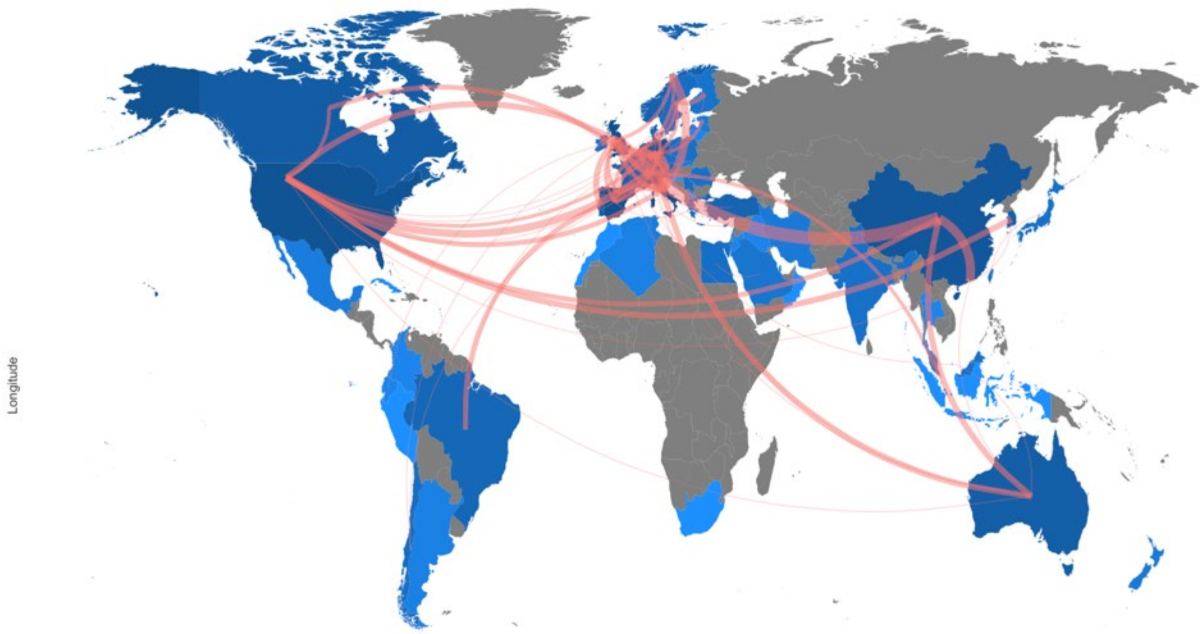

Figure 10.12. Country collaboration map. (Source: Author).

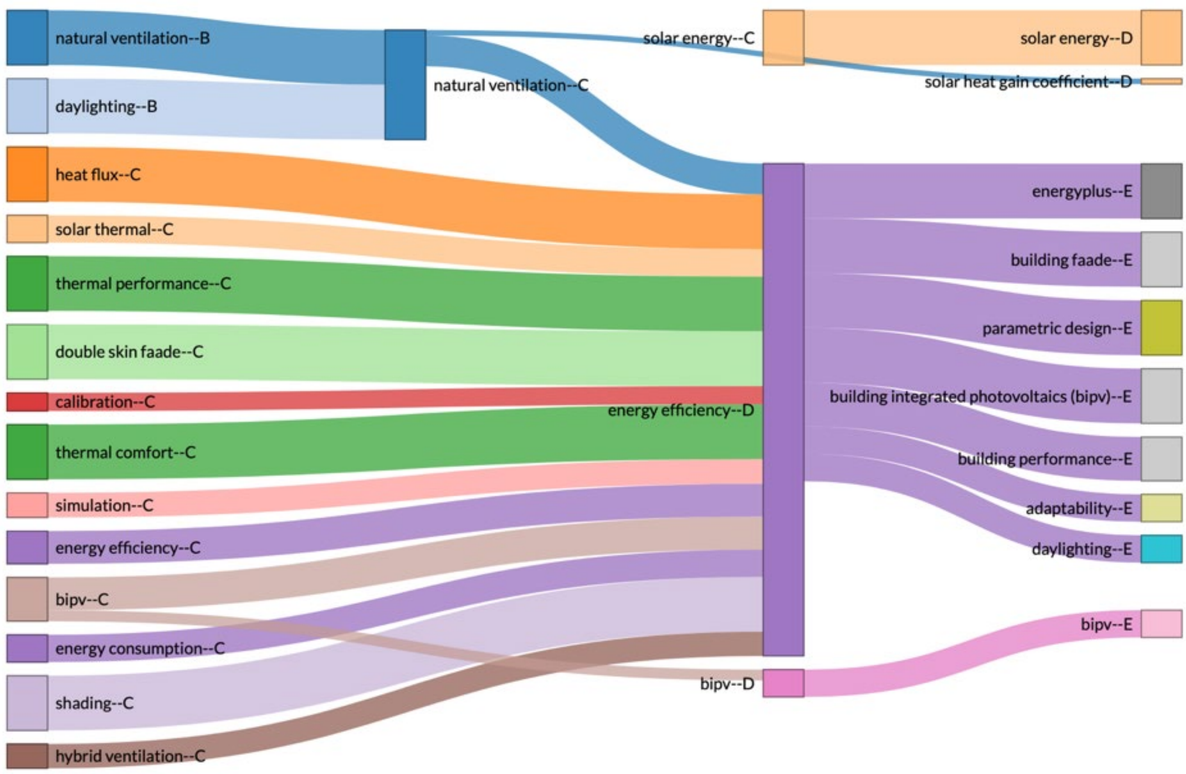

Figure 10.13. Thematic map of the evolution of Author's Keyword in the period of 1998-2003-2010-2018. (Source: Author).

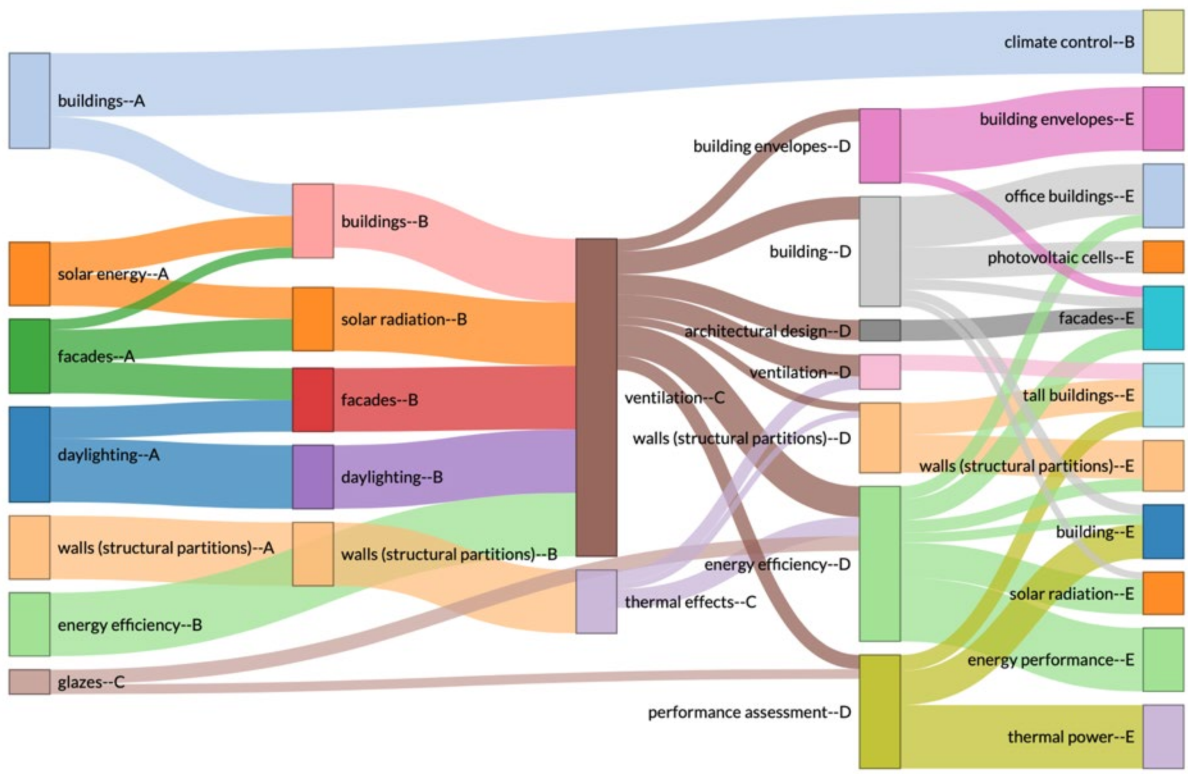

Figure 10.14. Thematic map of the evolution of Keyword Plus in the period of 1998-2003-2010-2018. (Source: Author).

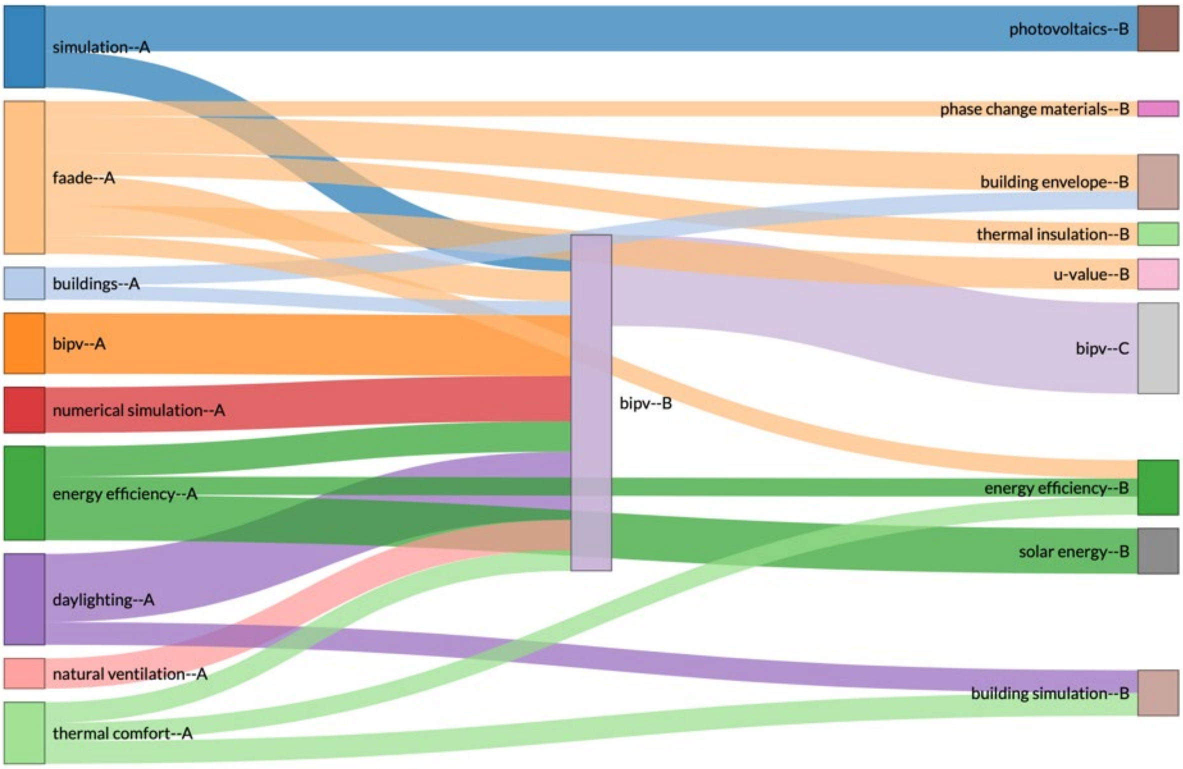

Figure 10.15. Thematic map of the evolution of Author's Keyword in the period of 2015-2018. (Source: Author).

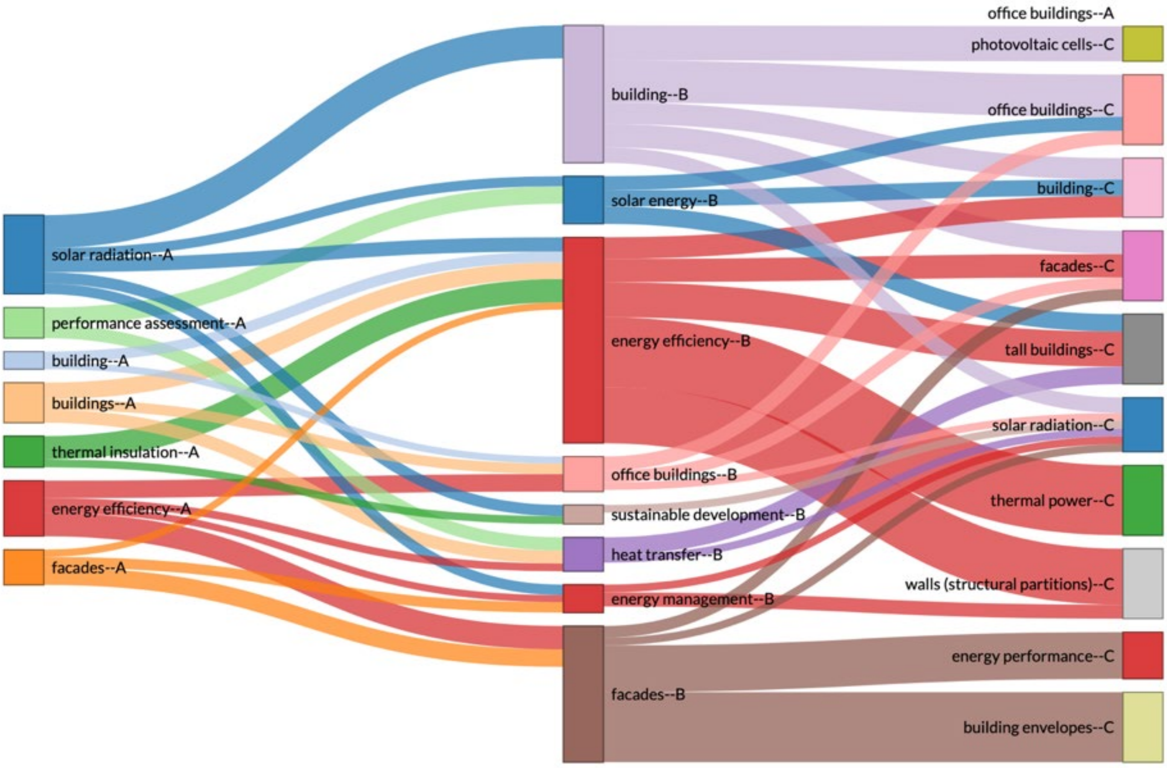

Figure 10.16. Thematic map of the evolution of Keyword Plus in the period of 2015-2018. (Source: Author).

Appendix B. Shape Grammars Literature Review

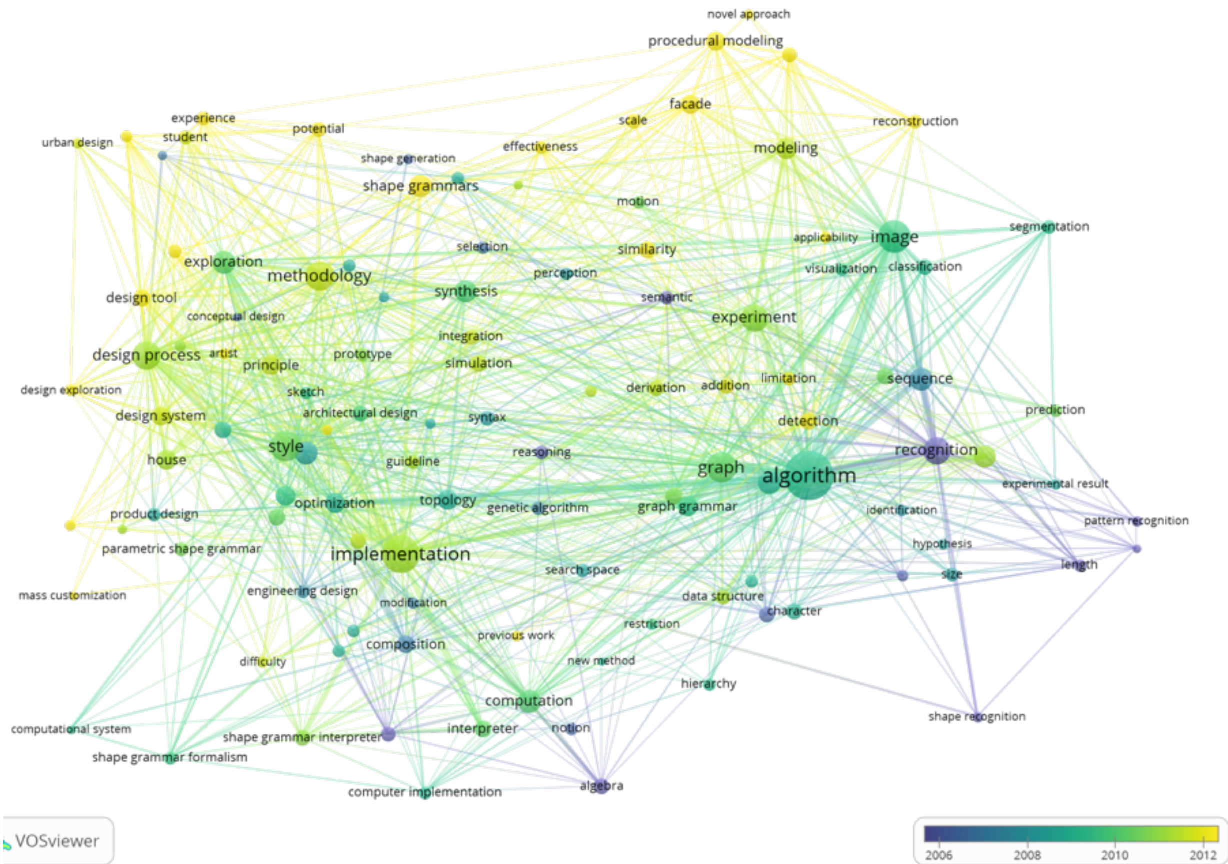

Figure 10.17 Co-occurrence network of terms in the field of Shape Grammars. (Source: Author).

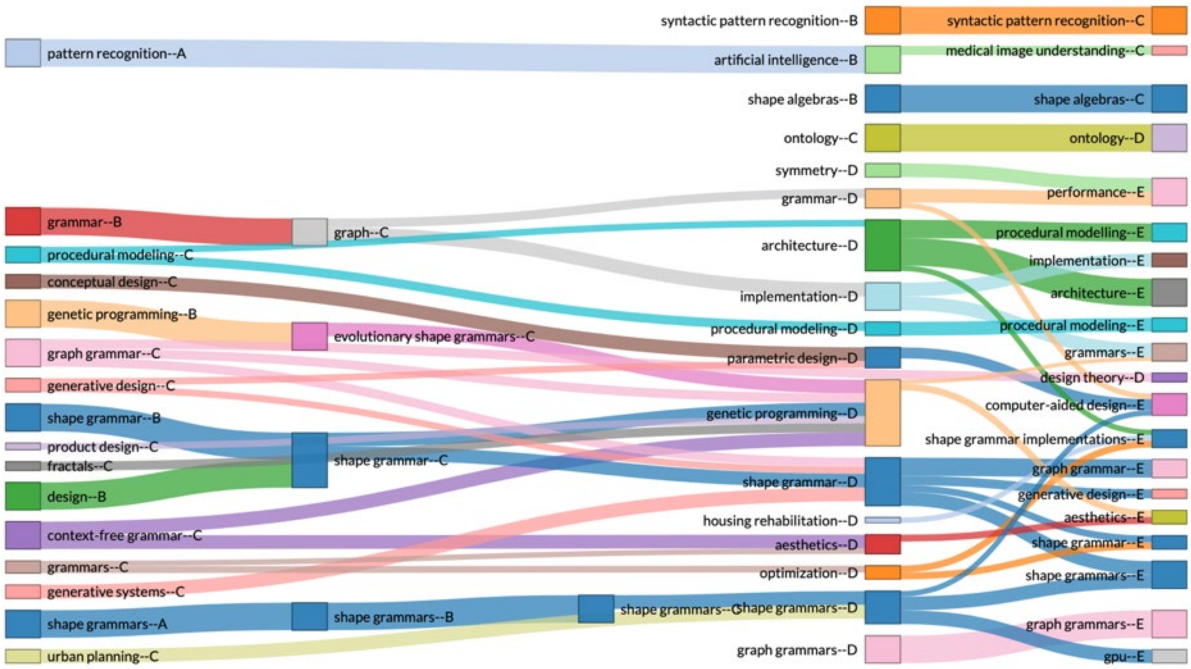

Figure 10.18 Thematic map of the evolution of Author's Keyword in the period of 1998-2003-2010-2018. (Source: Author).

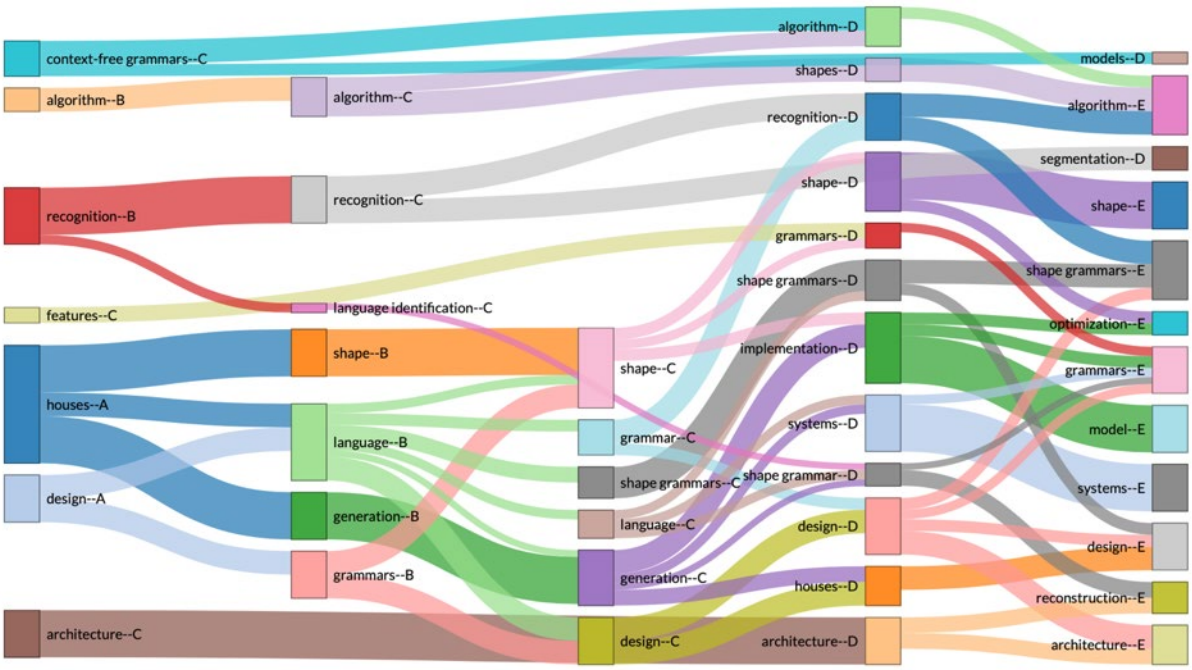

Figure 10.19 Thematic map of the evolution of Keyword Plus in the period of 1998-2003-2010-2018. (Source: Author).

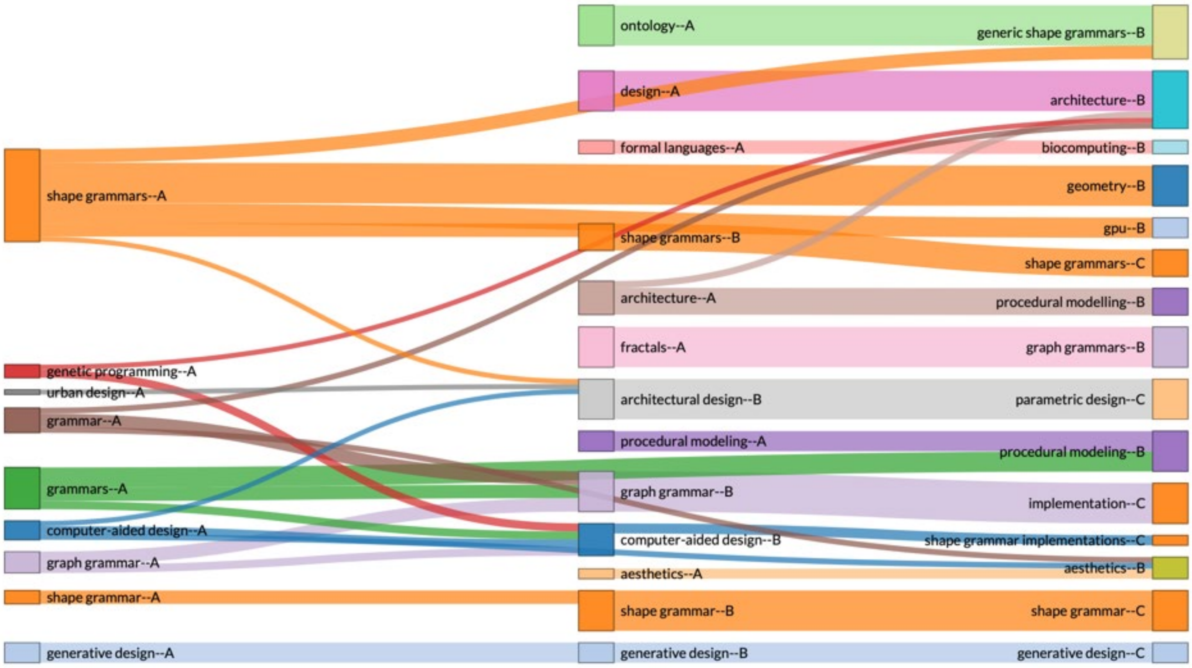

Figure 10.20 Thematic map of the evolution of Author's Keyword in the period of 2015-2018. (Source: Author).

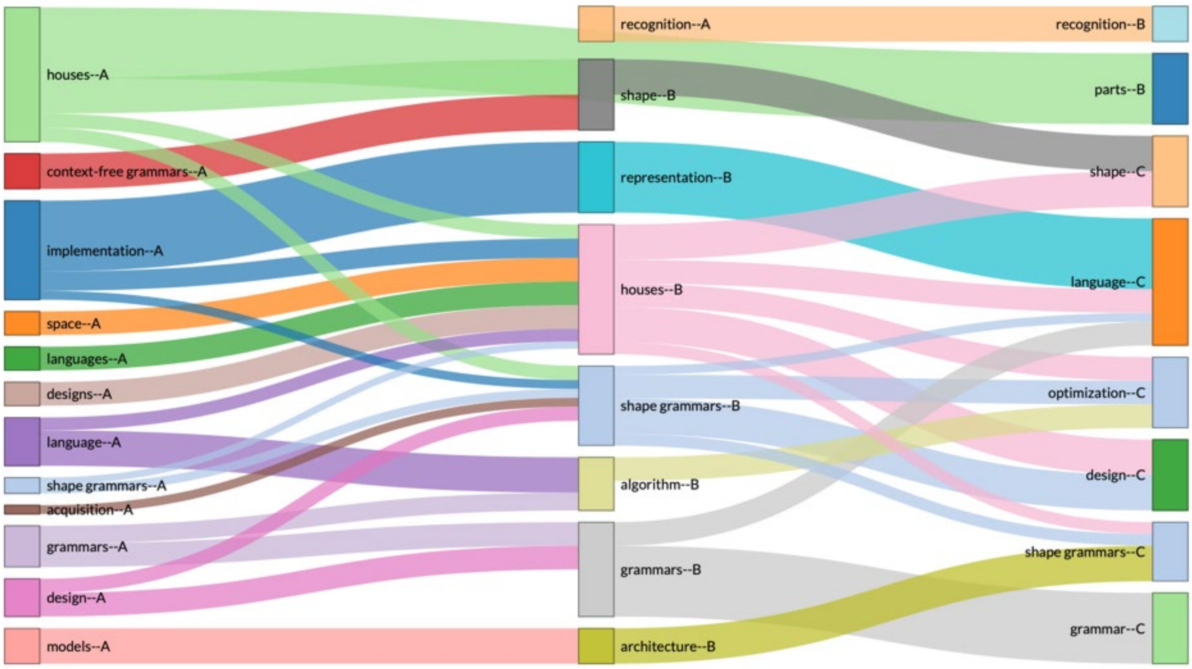

Figure 10.21 Thematic map of the evolution of Keyword Plus in the period of 2015-2018. (Source: Author).

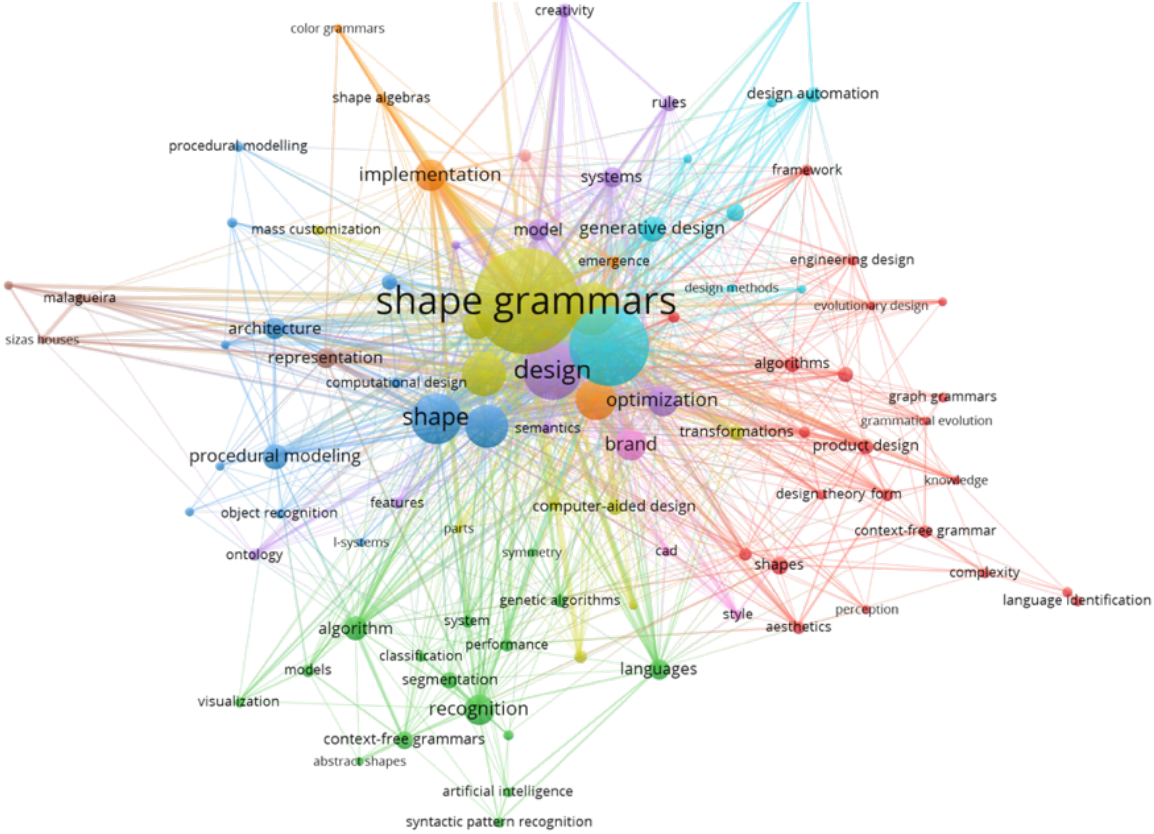

Figure 10.22 Clustered group of terms in the field. (Source: Author).

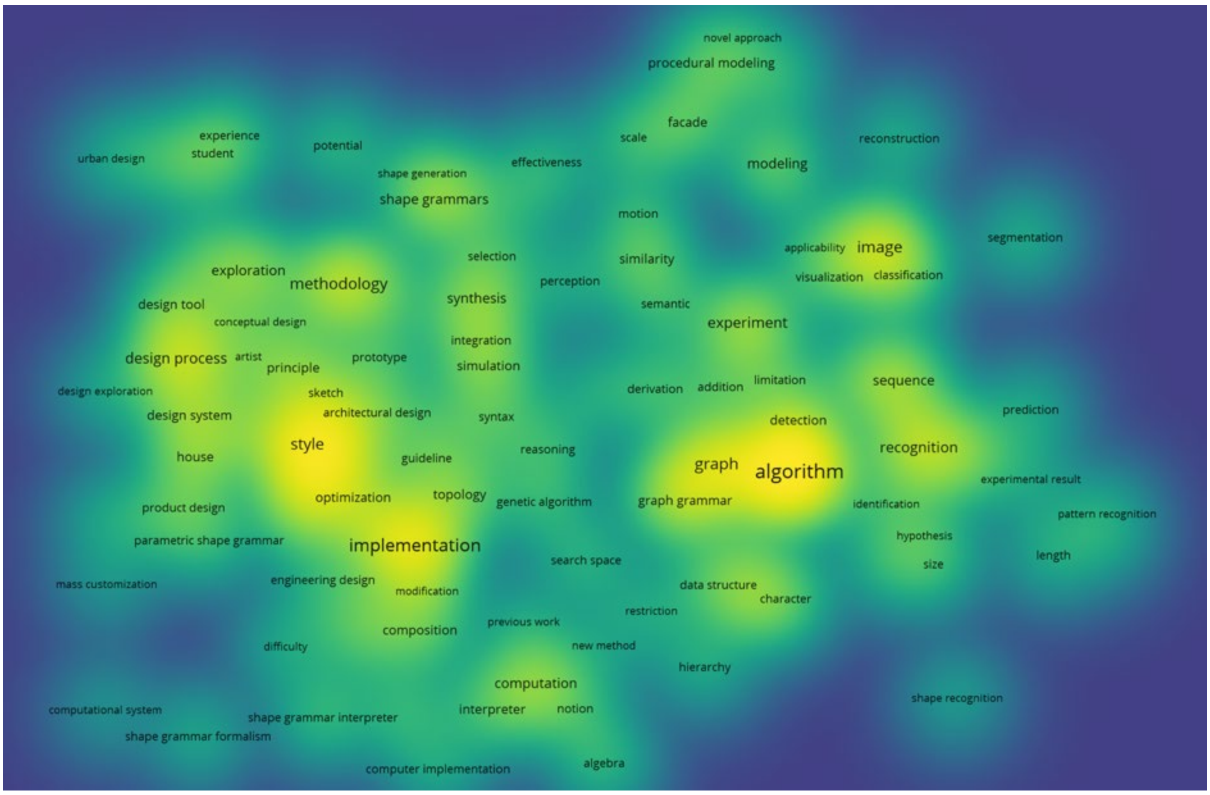

Figure 10.23

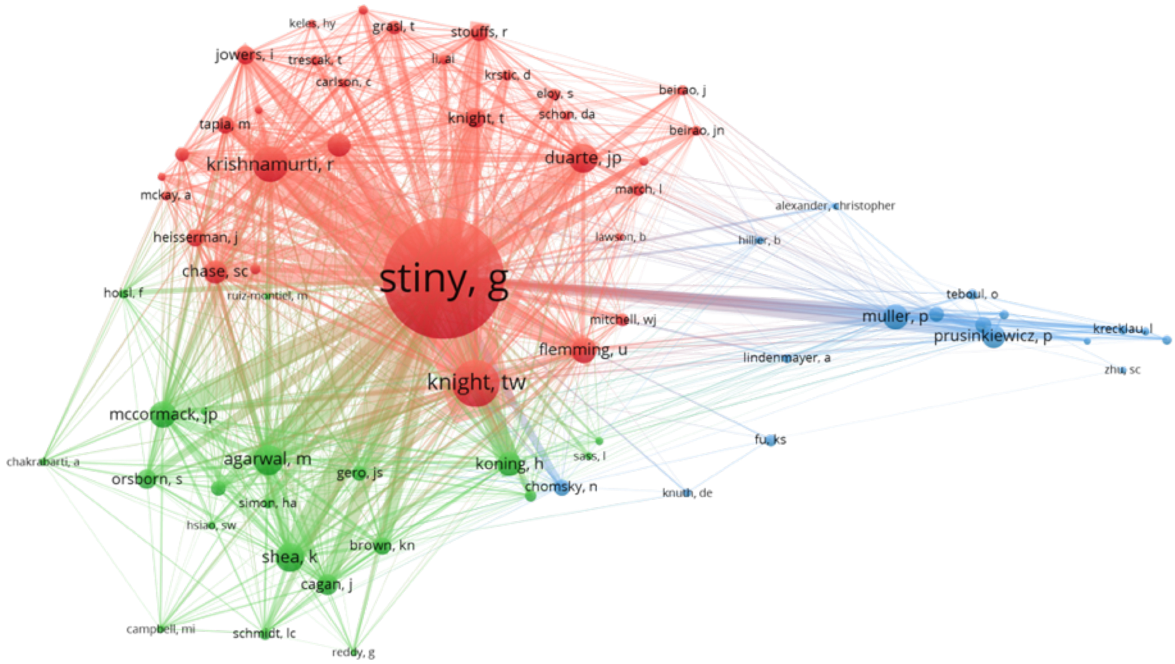

Figure 10.24 The most influential authors. (Source: Author).

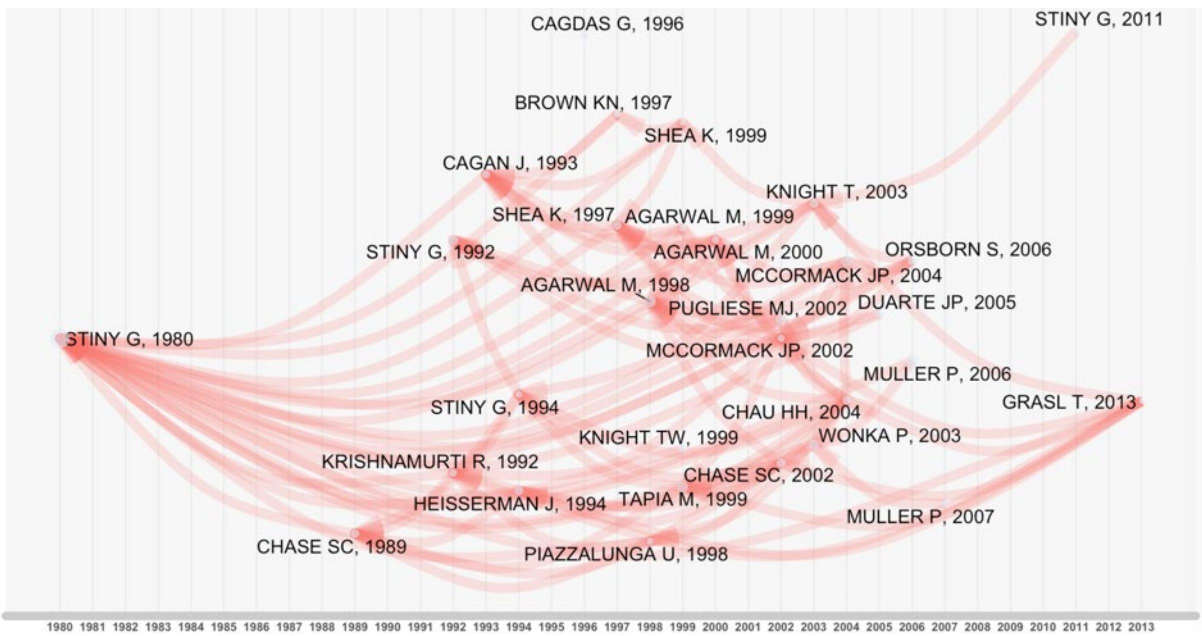

Figure 10.25 Historical direct citation network. (Source: Author).

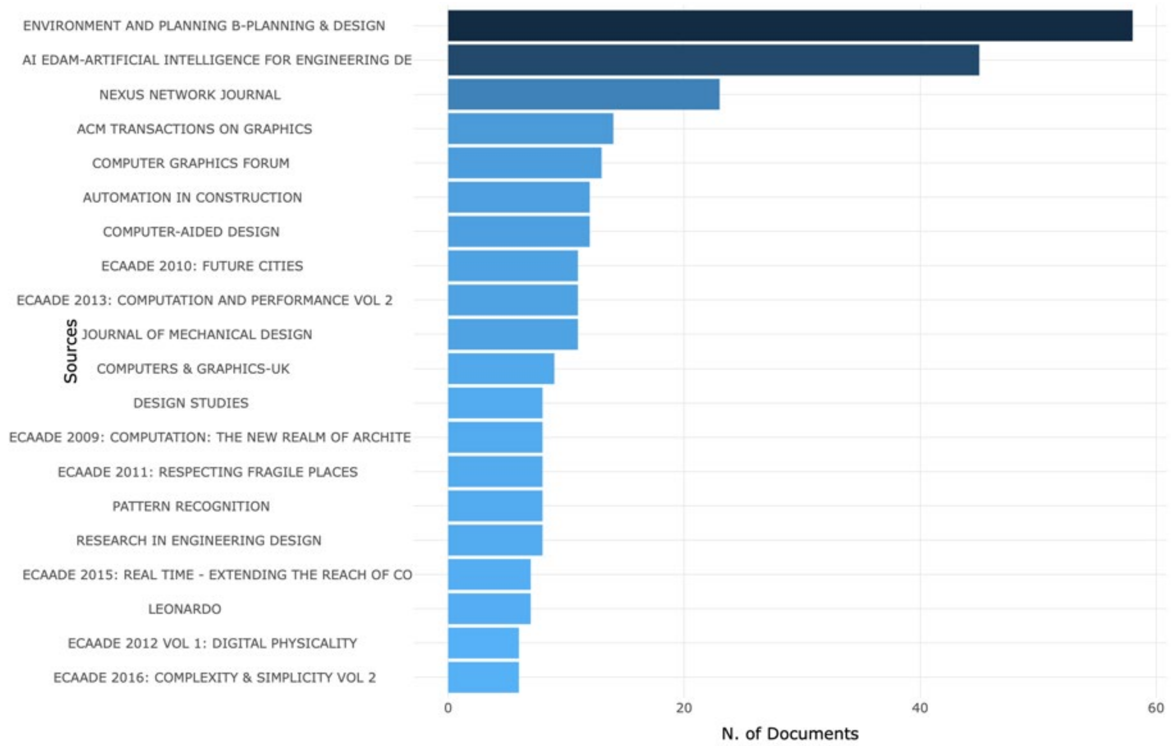

Figure 10.26 Most relevant sources. (Source: Author).

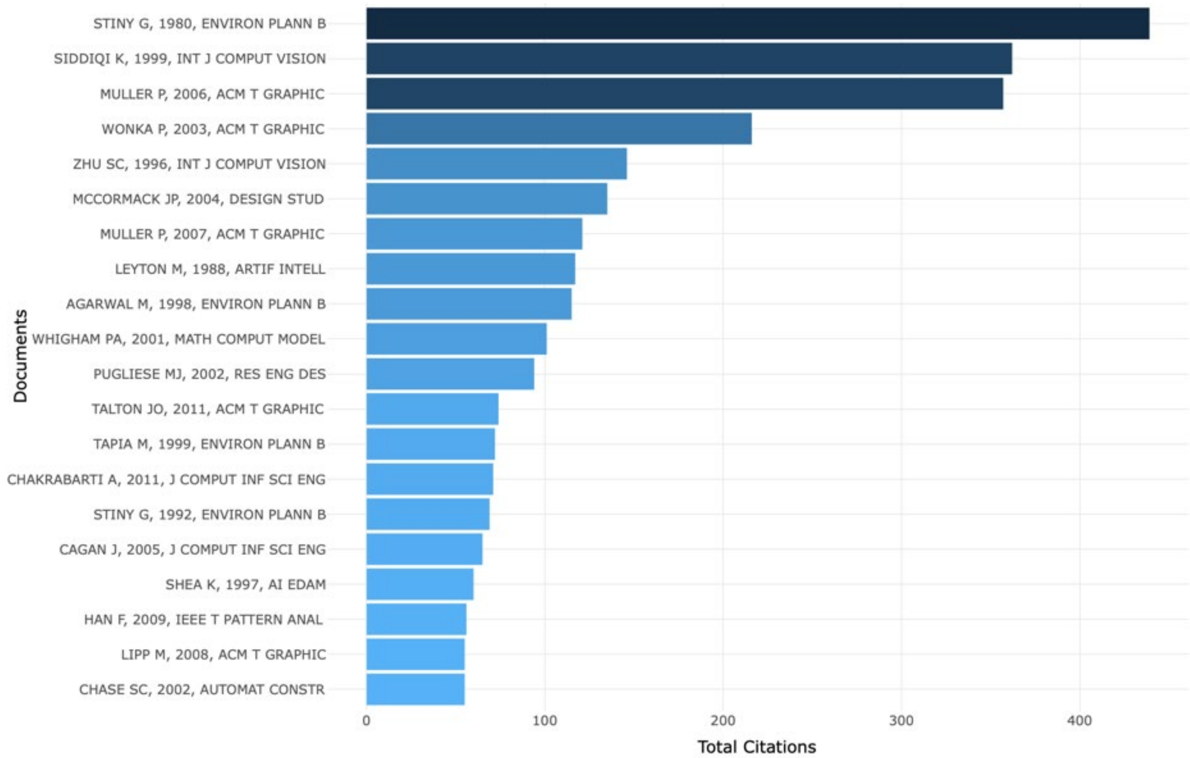

Figure 10.27 Most cited documents. (Source: Author).

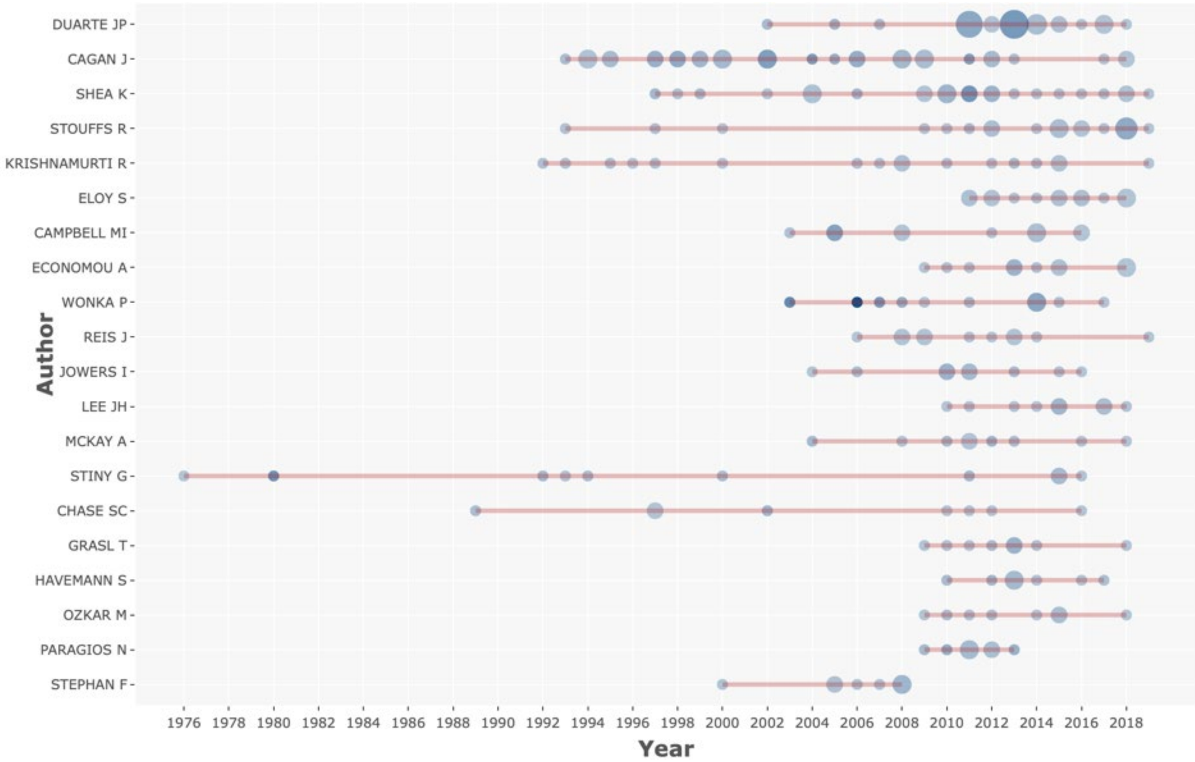

Figure 10.28 Top-authors' production over time. (Source: Author).

Figure 10.29 Authors' keywords. (Source: Author).

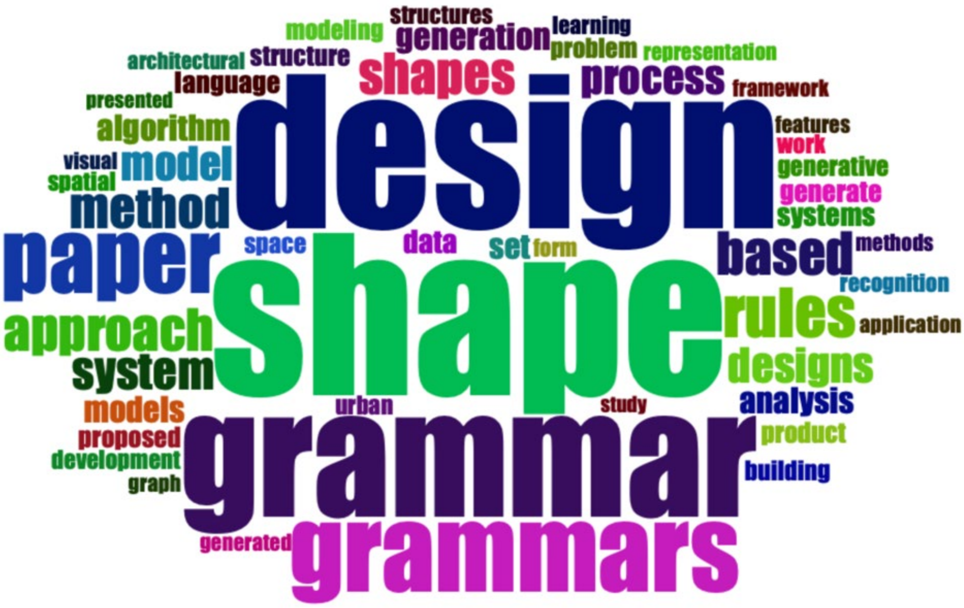

Figure 10.30 Keyword Plus. (Source: Author).

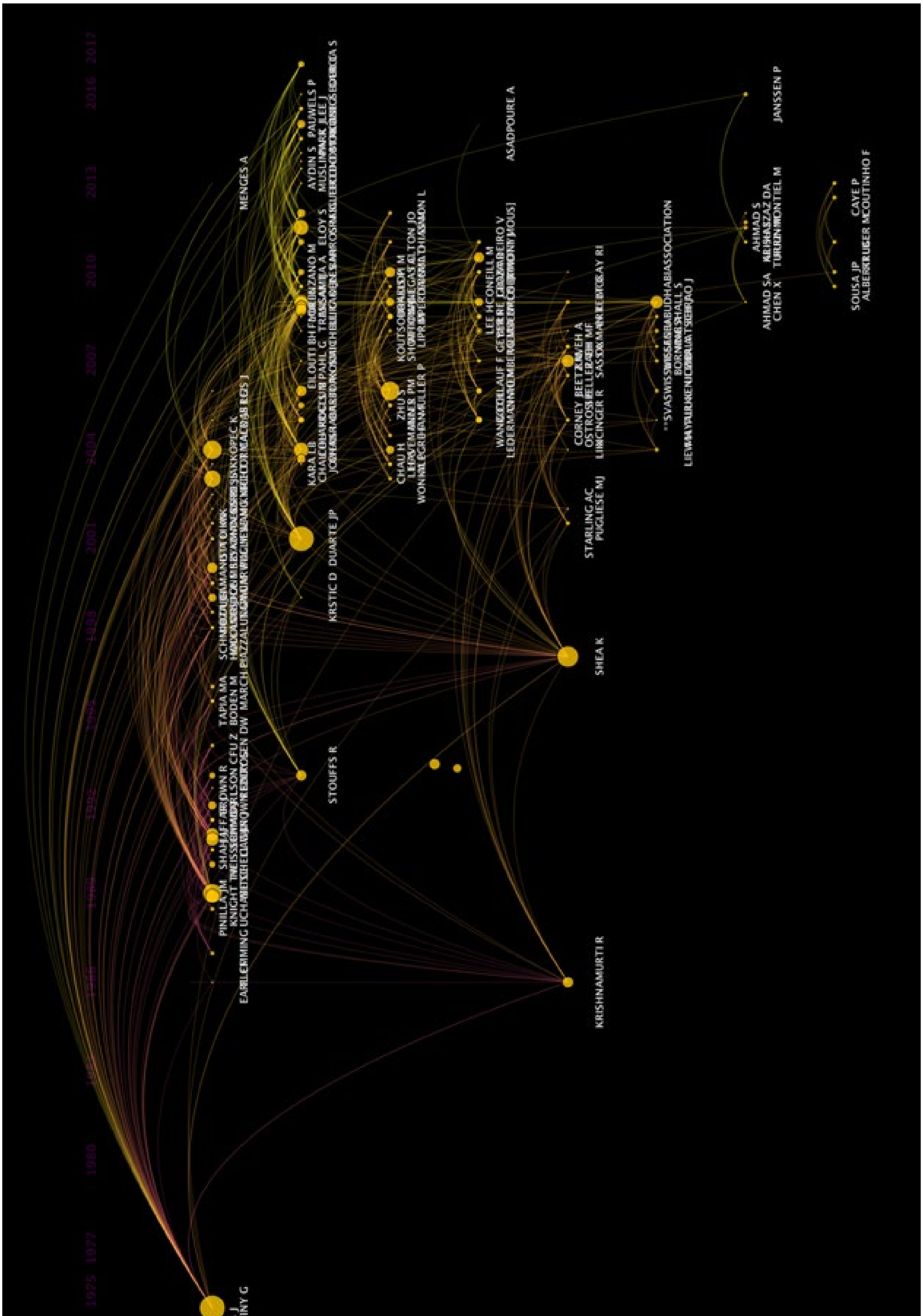

Figure 10.31 The history of Shape grammars. (Source: Author).

Appendix C. Generative Patterns

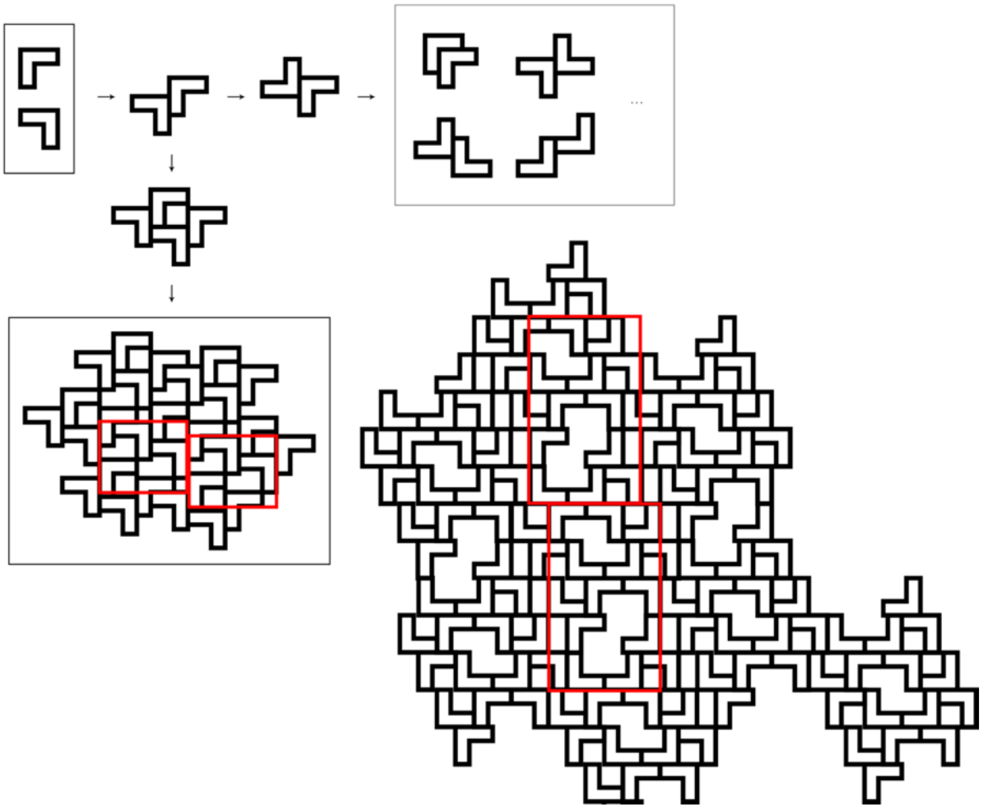

Figure 10.32: A new pattern achieved from basic rules applied to emergent L-shape. (Source: Author).

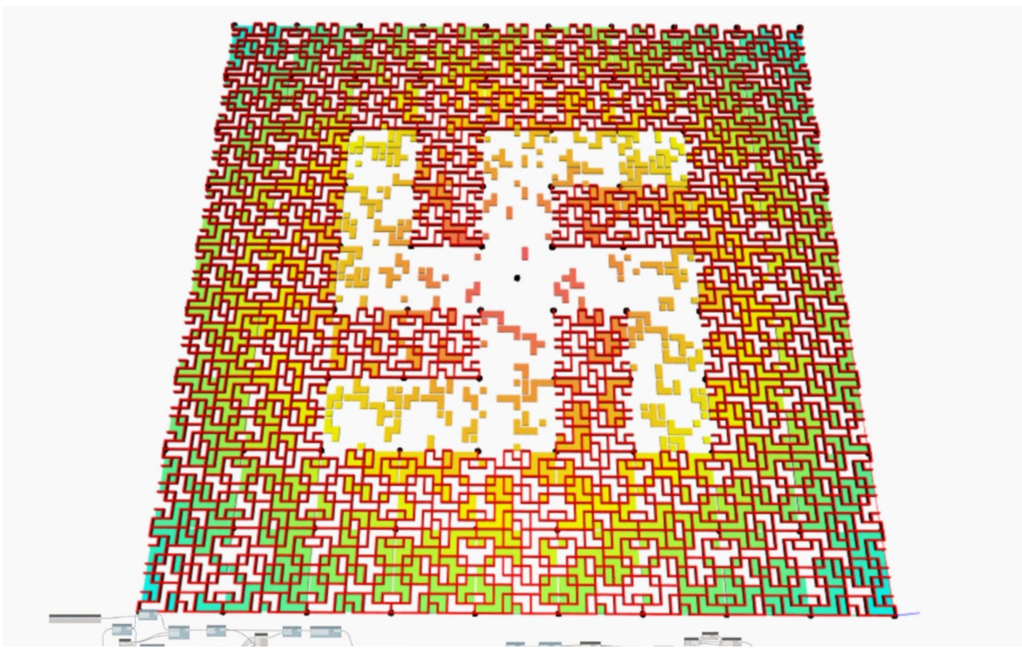

Figure 10.33 Swastika aperture, generated from swastika motif. An expression of a cultural-modern pattern (Source: Author).

Appendix D. Weather Data

Table 10.1 International Climate Zone Definitions. (ANSI/ASHRAE/IESNA Standard 90.1-2007).

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Table 10.2 International Climate Zones. (ANSI/ASHRAE/IESNA Standard 90.1-2007).

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Figure 10.34 Map of the annual average of daily global horizontal irradiation (left) and direct normal irradiation (right) (kWh m2/day) in Vietnam (Source: IDEA).

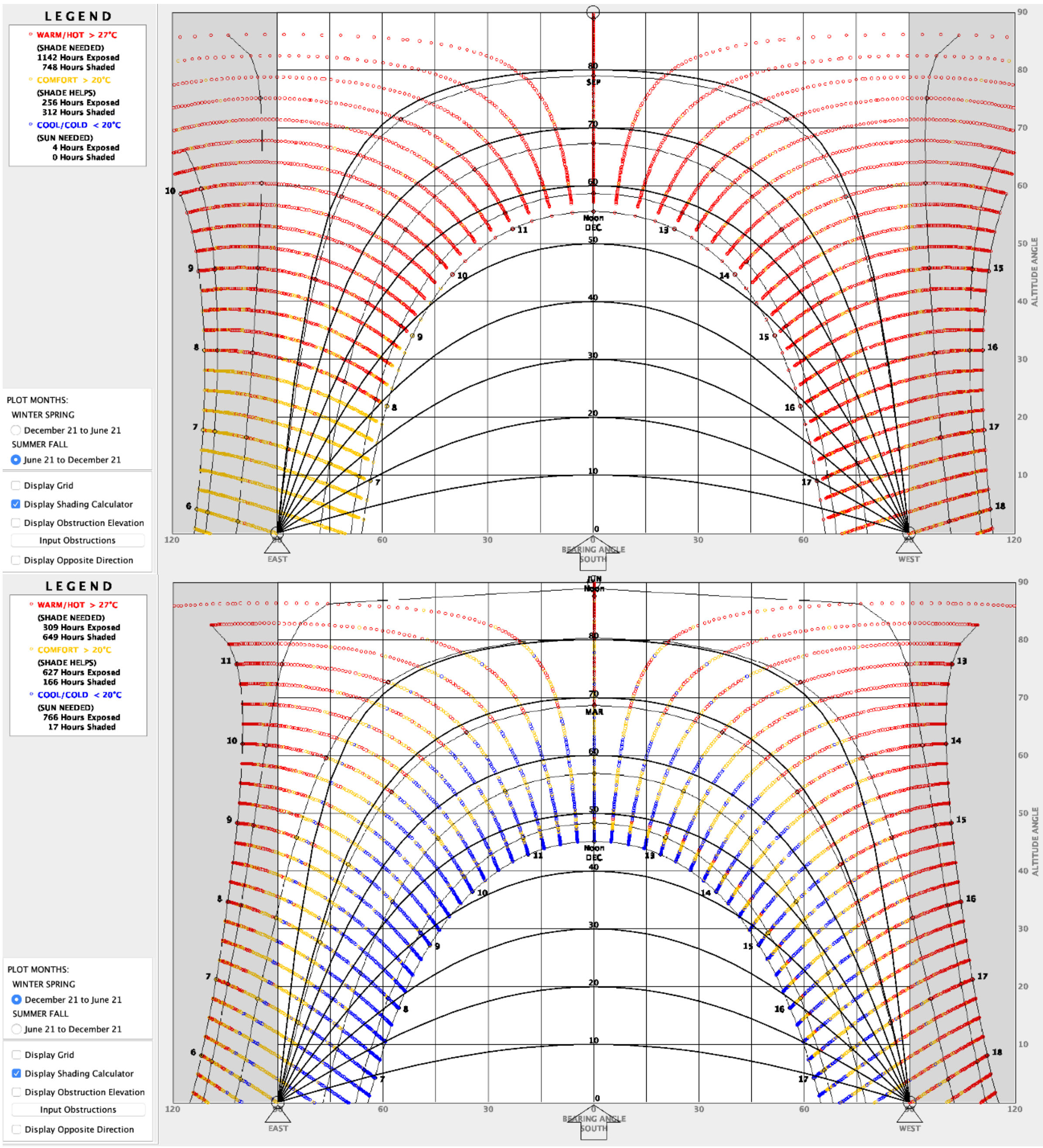

Figure 10.35 Sun shading chart of Hanoi and Saigon, indicating the difference in solar altitudes and dry-bulb temperature between two cities. (Source: Author – using Climate Consultant (free) software).

Table 10.3 Annual statistics of solar altitudes in the three cities. (Source: Author – using (licensed) IES-VE software).

Month	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
Jan		4.09	16.44	27.81	37.53	44.55	47.48	45.51	39.21	29.93	18.83	6.64	
Feb		6.2	19.33	31.72	42.77	51.3	55.37	53.48	46.38	36.1	24.12	11.22	
Mar		11.41	25.14	38.45	50.82	60.97	65.9	62.61	53.25	41.2	28.04	14.38	0.47
Apr	4.09	17.99	31.97	45.89	59.49	71.9	78.17	70.79	58.16	44.5	30.57	16.59	2.7
May	8.25	21.77	35.52	49.41	63.37	77.31	87.07	74.09	60.12	46.16	32.3	18.6	5.15
Jun	8.88	22.06	35.52	49.15	62.89	76.65	87.8	75.29	61.52	47.79	34.17	20.73	7.59
Jul	7.11	20.39	33.95	47.69	61.55	75.48	89.37	76.59	62.66	48.79	35.04	21.47	8.15
Aug	4.75	18.5	32.41	46.39	60.29	73.71	82.56	74.08	60.69	46.79	32.81	18.9	5.15
Sep	2.88	16.85	30.71	44.25	56.95	67.29	70.88	64.65	53.32	40.29	26.62	12.71	
Oct	0.72	14.31	27.45	39.72	50.32	57.52	58.86	53.69	44.16	32.41	19.55	6.11	
Nov		10.09	22.33	33.43	42.54	48.34	49.39	45.35	37.38	26.96	15.1	2.4	
Dec		5.94	17.89	28.7	37.64	43.62	45.41	42.55	35.76	26.29	15.16	3.01	
Jan		7.74	20.47	32.27	42.43	49.69	52.33	49.42	41.97	31.7	19.84	7.08	
Feb		9.32	22.86	35.75	47.38	56.39	60.29	57.22	48.69	37.3	24.52	11.04	
Mar		13.81	27.99	41.84	54.91	65.9	70.77	65.55	54.43	41.31	27.45	13.26	
Apr	5.16	19.46	33.83	48.21	62.47	76.09	82.55	71.45	57.46	43.14	28.75	14.4	0.14
May	8.55	22.41	36.45	50.59	64.78	78.92	85.79	72.08	57.89	43.71	29.61	15.65	1.91
Jun	8.76	22.26	35.94	49.71	63.41	76.49	82.66	72.04	58.6	44.85	31.1	17.47	4.08
Jul	7.11	20.73	34.56	48.48	62.42	76.08	84.74	73.77	60.01	46.07	32.15	18.36	4.78
Aug	5.43	19.55	33.82	48.17	62.55	76.88	86.92	73.69	59.33	44.95	30.62	16.38	2.29
Sep	4.58	18.96	33.28	47.37	60.86	72.23	75.25	66.44	53.56	39.66	25.42	11.06	
Oct	3.39	17.38	30.99	43.84	55.08	62.66	63.23	56.44	45.55	32.85	19.33	5.37	
Nov	0.47	13.76	26.42	37.99	47.54	53.46	53.9	48.7	39.56	28.22	15.69	2.47	
Dec		9.79	22.11	33.33	42.65	48.75	50.1	46.28	38.41	28.03	16.2	3.51	
Jan		9.12	22.35	34.86	45.99	54.41	57.9	54.96	46.88	35.92	23.5	10.32	
Feb		9.9	23.94	37.51	50.14	60.58	65.81	62.65	53.21	40.98	27.6	13.66	
Mar		13.42	28.03	42.47	56.49	69.21	76.34	70.33	57.87	43.92	29.51	14.91	0.22
Apr	3.31	17.91	32.57	47.28	62.01	76.73	87.89	73.6	58.88	44.15	29.45	14.79	0.21
May	5.88	19.97	34.15	48.33	62.37	75.61	81.65	71.24	57.56	43.44	29.24	15.09	1.06
Jun	5.7	19.38	33.15	46.85	60.19	72.13	77.41	69.84	57.42	43.96	30.23	16.47	2.82
Jul	4.18	18.01	31.95	45.87	59.56	72.27	79.3	71.89	59.12	45.41	31.49	17.55	3.72
Aug	3.16	17.56	32.05	46.6	61.17	75.65	86.97	74.45	59.95	45.38	30.84	16.35	1.96
Sep	3.43	18.16	32.88	47.52	61.93	75.37	80.88	70.11	56.07	41.54	26.86	12.13	
Oct	3.43	17.83	31.98	45.63	58.13	67.46	68.89	61.22	49.31	35.88	21.84	7.49	
Nov	1.42	15.13	28.37	40.75	51.42	58.56	59.58	53.95	44.06	32.05	19	5.4	
Dec		11.45	24.31	36.28	46.59	53.76	55.75	51.74	43.26	32.25	19.91	6.84	

Appendix E. Simulation

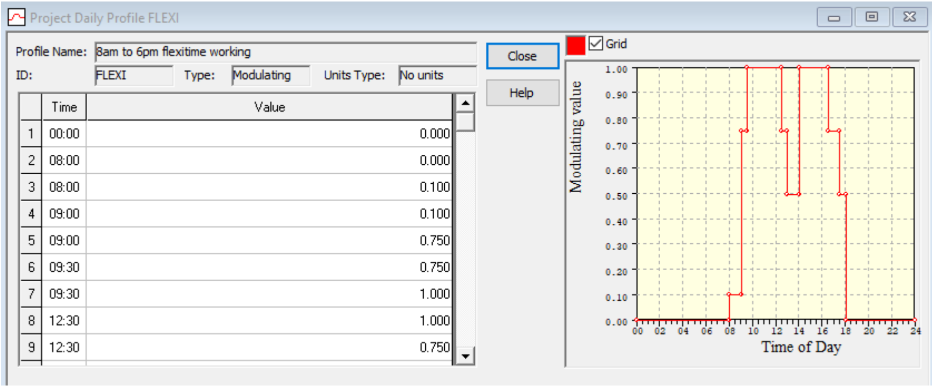

Figure 10.36 Equipment Schedule. (Source: Author).

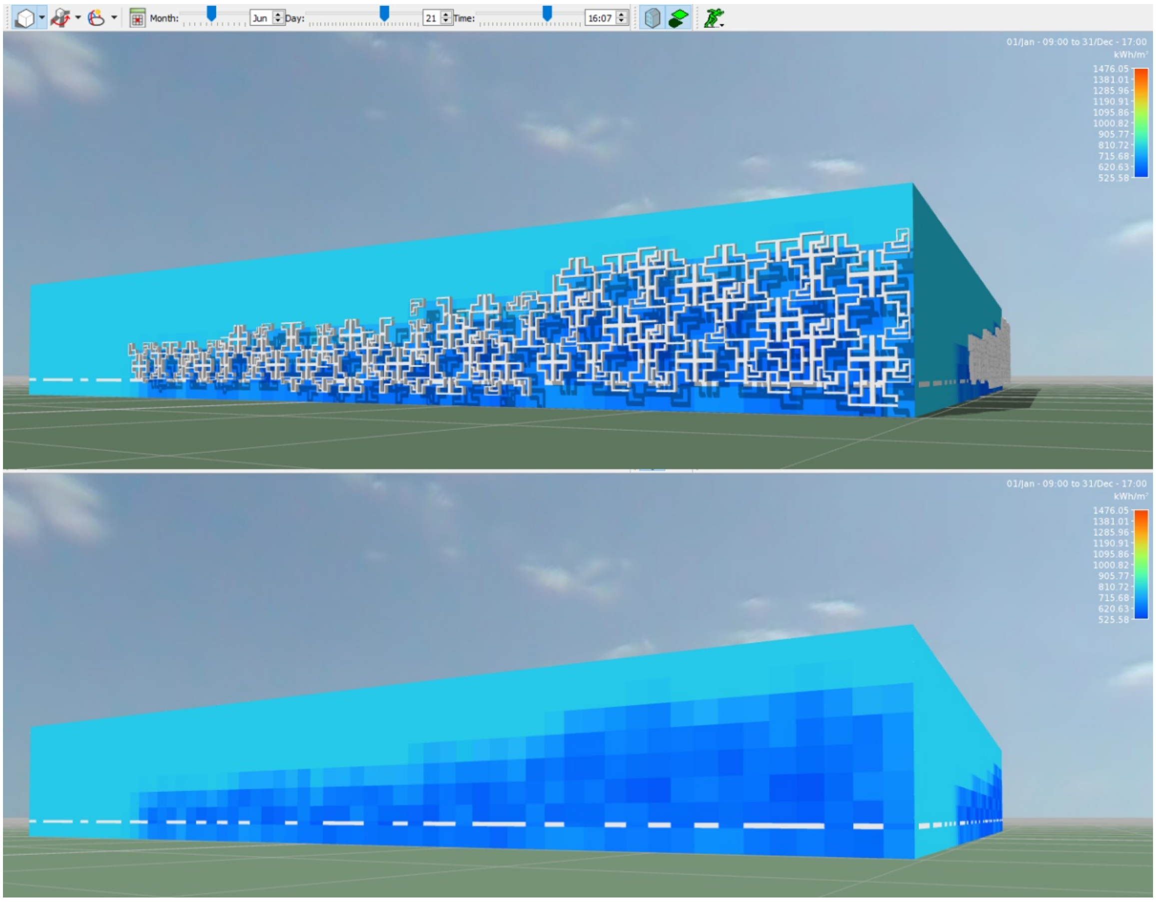

Figure 10.37 Cumulative solar radiation on the external window of westside space. (Source: Author).

For example, at 10 o'clock in the morning, the optimum solution is the shading device opens 50% and locates at downright zone of the external screen. 10% of the whole will be moved to a corner, ready for action in another time. If the system asks for 40%, then 20% will be reduced.

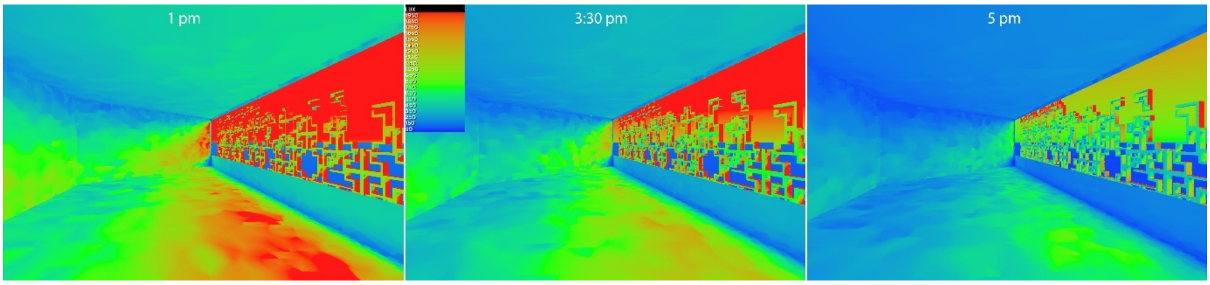

Figure 10.38 Images of illuminance levels in Westside space at three times in the afternoon. (Source: Author).

Figure 10.39 displays changes in daylight levels at 1 pm, 3pm and 5pm in the office. If the system is static, the DLs are decreased with the time goes on in the afternoon. This means artificial lights will be activated, resulting in an increase in lighting gains. The kinetic movement that consumes minimum energy will ensure both heating and cooling loads and lighting gains are maintained as lowest as possible. A small amount of lighting gains proves that an adequate amount of natural light is available in the room.

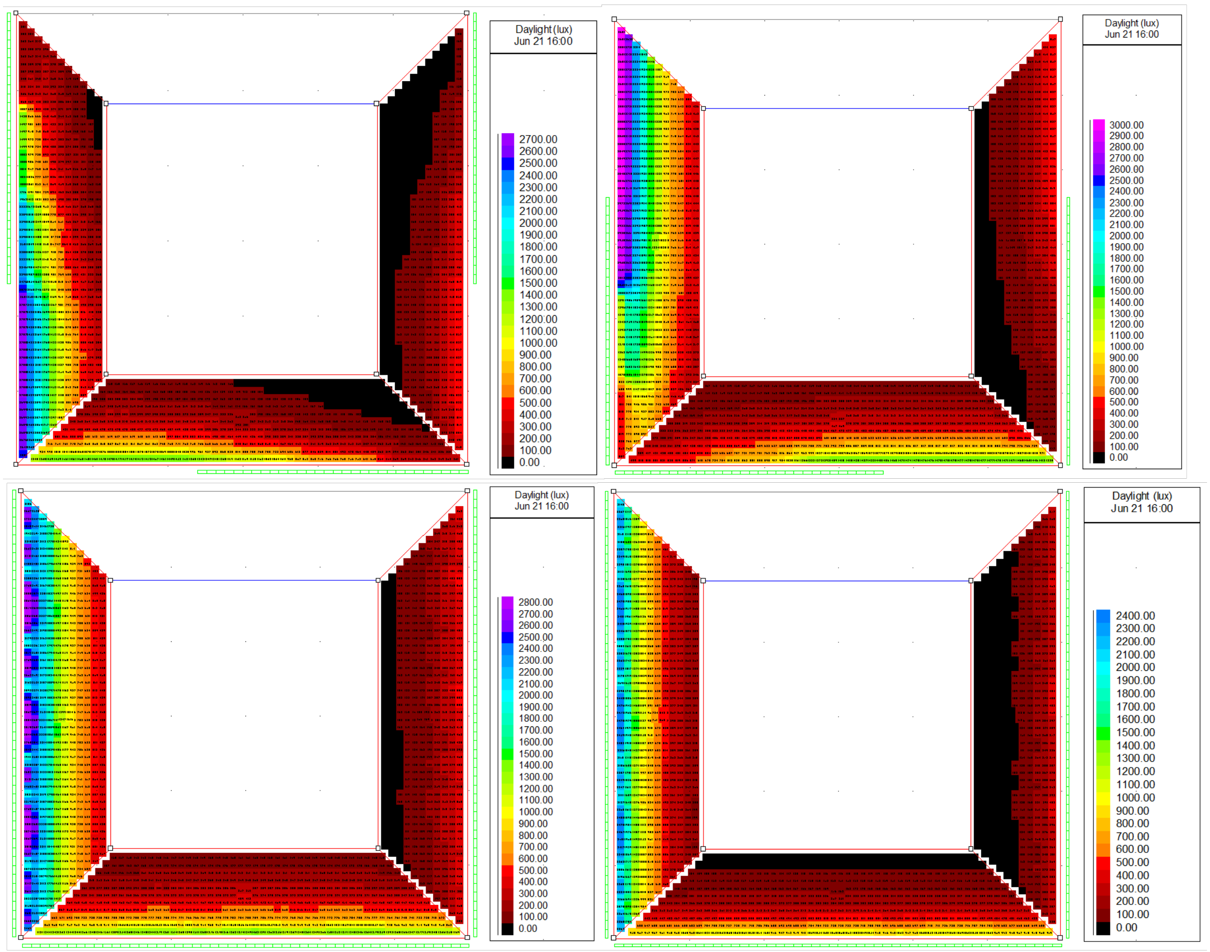

Figure 10.40 Daylight illuminance on work plane (0.75m) on three sides (west, south, east) with four positions (up left, downright, down, up). (Source: Author).

In the same context, 12 different DLs are presented in Figure 10.41, showing daylight performances on three sides in four configurations. It also reveals that patterns of light are changing too. This is interesting because it offers contrasts that make human eyes in comfort as well as make the office looking lively. This reflects the value of daylight architectural design since the beauty of an interior space fundamentally comes from the contrast of light (Lou Michel, 1995).

Appendix F. Related Published Works

The Gentle House – Hanoi, Vietnam
https://www.archdaily.com/567952/the-gentle-house-ngoc-luong-le

Content removed due to copyright reasons

https://www.designboom.com/architecture/ngoc-luong-le-v-architecture-gentle-house-hanoi-vietnam-11-17-2014/

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Dragonfly Park – Hoi An, Vietnam
https://www.domusweb.it/en/architecture/2015/03/26/dragonfly_park.html

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https://www.archdaily.com/608876/dragonfly-park-v-architecture

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