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Original Article

Study on Parameters and Variables of Courtyard and Degree of Impact Towards their Aspect through Adjacency Matrix

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Abstract *- Courtyards serve as significant spaces with anthropological and aesthetic value, and their use has evolved throughout time. A courtyard serves as a helpful architectural element since it is closely tied to the ideal environment in many aspects. Evaluating the courtyard's parameters and variables is the primary goal of the article; studying the courtyard requires a firm understanding of these principles. An adjacency matrix is created by combining the collected data and variables in order to obtain an influence towards the courtyard. There are two stages to the study: reviewing the literature, determining important parameters, variables, and aspects, and developing a template for an adjacency matrix. Qualitative data from literature-based investigations aid the identification of parameters and variables influencing the zone. In the second step, a case study research approach is used to examine the newly constructed matrix, concentrating on a vernacular architectural style from Tamil Nadu. The findings are useful in assessing the characteristics of the Courtyard, considering the parameters and variables and their effects on various aspects concerning the courtyard. They also provide a useful conclusion for future research on the Courtyard.*

Keywords *- Vernacular architecture, Courtyard, Parameters, Variables, Aspects, Adjacency matrix.*

1. Introduction

"Courtyard houses have an ancient history: examples have been excavated at Kahun, in Egypt, that are believed to be 5000 years old, while the Chaldean City of Ur, dating from before 2000 BC, was also comprised houses of this form" Written in Dwellings: The House Across the World by Paul Oliver. [1] Regarding the origin of the courtyard form, experts in architecture history and theory have differed, but it is still unclear how exactly it evolved. Generally speaking, In the Middle East, courtyard homes are more typical than anywhere else in the world. They consist of rooms encircling an open-to-sky court.

This concurs with the theory of Hinrichs and Schoenauer. [2] It may be possible that people who lived in prehistoric caves developed the courtyard-style home. It is a universal design that responds to people's need for seclusion and confinement. However, according to Hinrichs, the courtyard style of the home remains mostly unaltered by the passing of time, different civilizations, and different temperatures. As demonstrated by the dwellings in Mesopotamia, the Indus Valley, Egypt, China, and the Classical Roman and Greek eras, the courtyard shape is an ageless architectural style. The testimonies of Hinrichs, Oliver, Schoenauer, and Sullivan support this. [3] Oxford University Dictionary (n.d.) defines a courtyard as an open space that is completely or partially encircled by walls, houses, or other structures. However, according to the Cambridge Dictionary, A level outdoor space that is entirely or partially surrounded by a building's walls is called a courtyard. (Cambridge University n.d.). An open space without any covering that is encircled by walls or other buildings is called a courtyard. [4] According to archaeologist Sir John Marshall, homes from the Indus Valley Civilization (c. 2000-1500 B.C.E.) in India included courtyards. With the sky providing natural light and ventilation, the ground and higher floors of rooms were arranged around these courtyard residences. Open courtyards, incorporating chambers, were the foundation for the design of homes at Mohenjo-Daro and across ancient and historic Asia. In India today, this notion is still widely held.[5] India's traditional courtyard homes were created over time to accommodate the utilitarian, sociocultural, religious, microclimatic, thermal, energy-saving, and financial demands of its occupants.

These homes may achieve these goals despite having limited resources and restricted building technology because they have appealing exterior and interior architectural features. [6] Courtyards are essential spaces within buildings

where people interact with their surroundings. They are well-planned, efficient, and responsive to cultural and climatic needs. Courtyards are influenced by human bio-social, psychological, and cultural characteristics and are crucial for sustainable development. They serve various functions, including sleeping, drying, cleaning, cooking, and cultivating plants. They are especially important for elderly individuals and those with mobility impairments.

A courtyard's soil, minerals, sky, water, plants, and human waste can all be thought of as components of an ecosystem. The sun, wind, rain, and sky they bring in have an impact on the conduct of the locals. Courtyards' tangible and metaphorical qualities have an impact on how cities develop. [7] A courtyard's thermal behavior may be influenced by a number of factors, including thermal massing, material, shade, and water features. The courtyard typology offers a thorough solution to the problems with current construction forms caused by climate change. Depending on the land parcels in new structures, the courtyard's size plays a major role in determining its use and usefulness.

Typologies of courtyards can accommodate the anthropological and cultural needs of renters. [8] Buildings provide better natural ventilation and heat dispersion with courtyards. Their design optimizes thermal comfort by managing the microclimate. Because it influences both indoor and outdoor spaces, the layout of courtyards in architectural design-including their size, form, scale, and proportion—is crucial. [9] The aspect ratio of the building and the courtyard affects the thermal comfort of building occupants.

The aspect ratio of the structure influences how heated the courtyard is, resulting in a sharp temperature gradient between the various floor levels. The aspect ratio of the courtyard determines the shadow area yield of a floor level. An awkward choice of courtyard aspect ratio can result in open areas being exposed to direct sunshine, which can cause heat waves and raise the mean surface temperatures of buildings.

[10] Three main aspects: The courtyard's organizational standards, climate benefits, psycho-social benefits, and cultural advantages. According to the research, having a courtyard in a home helps its occupants adjust to changing needs and lifestyle changes. The results also demonstrated how Western socio-cultural influences have affected the increasing proportion of residents residing in newly constructed homes. The courtyard, however, continues to be highly coveted since it offers the characteristics of the ancient lifestyle and draws a large number of occupants. In terms of security, serenity, enjoyment, enjoyment, and visual and auditory seclusion, the center courtyard was deemed satisfactory. [11] The integration of courtyards in buildings has been practised throughout history worldwide. Studies on this specific architectural element articulate numerous perspectives, implying different ideologies about courtyards and the significance they hold. Background study leads us to the conclusion that courtyards are historically significant architectural features with a diverse variety of internal details.

This study aims to identify the many courtyard qualities, together with their associated metrics and variables, and to explore the extent to which each specification is modified. Studying parameters and variables in the field of courtyard research is crucial because a comprehensive examination of these factors provides us with the best knowledge of the layers of the courtyard in a constructed structure.

In order to grasp the inherent qualities of the courtyard, we prefer to cover the many parts of the study conducted worldwide. Specifically, this study aims to identify the cumulative aspects, variables, and parameters that are suggested by a matrix.

2. Research Objective

- To conduct literature research in order to establish the criteria of courtyard design.
- To group the parameters into conceptually understandable topics.
- To assess each courtyard design criteria and aspect's applicability in a given geographic area.
- To make suggestions based on a study of the literature and a quantitative examination of every variable and parameter.

The primary objective is to elucidate the study areas using two distinct stages of investigation, commencing with an exhaustive analysis of the available literature and concluding with the determination of aspects, parameters, and variables.

The gathered information is utilized to build the courtyard's adjacency matrix, which helps to clarify the connection between the courtyard's variables and parameters and determines how much of an impact they have on it. With the case example as a guide, the parameters and variables, together with the same degree of impact, have been found.

3. Methodology of Literature Review

The research methodology for this paper starts with the classification of different publications and studies on courtyard buildings (Table 1). By organizing recent research, other scholars can locate pertinent references in various approaches to studying courtyard architecture. The innovative part of the methodology is creating a framework for future studies that will support any critical analysis of

Courtyards (based on literature and case testing), which architects can use to advise design decisions.

Table 1. The table consists of a list of journals which has been considered for literature overview

Author and Year	Research Methodology	Key Parameters
(Soliman & Elkhateeb, 2022)	Parametric study through qualitative methods and stimulation is done to evaluate quantitative data.	Courtyard, Durqa'a, Enclosure, Degree Prospect, Refuge: Mamluk Architecture
(Xu et al., 2018)		Courtyard Design: Aspect Ratio, Layout, Ecological Effect, and Ecological Buffer Area
(Bana Eid et al., 2022)		Courtyards, Solar Energy, Natural Ventilation, Thermal Comfort, and Air Quality
(Qianqian Sun et al., 2022)		Long strip houses, natural ventilation, a courtyard, a hot and humid climate, and thermal performance
(Fatma Abass et al., 2017)		Courtyard Form, Evolution, and Functions.
(AMR Bagneid, 2006)	Parameter study, literature overview, methodology and simulation to evaluate the qualitative and quantitative data.	Courtyard House, N Hot-Arid Climates And Temperate Climates, FD Microclimate/DOE-2 Simulation, Passive Cooling Performance
(Gupta & Joshi, 2021)		Courtyard Typology, Bye-Laws, Microclimate, High Density, and Sustainability
(Gangwar & Kaur, 2020)		Climate modification, globalization, courtyard homes, behavioral, environmental, thermal comfort, and natural light
(López-Cabeza et al., 2022)	Both qualitative and quantitative data, simulation and experimentation are used.	Building simulation, courtyard, microclimate, UTCi, passive strategies, and outdoor thermal comfort
(Taleghani et al., 2012)	Parameter study with case studies to evaluate the qualitative and quantitative data.	Courtyards, Climate Variations, Environmental Effects, and Architectural Features.
(Verma & Bano, 2023)		Activities, Composite Climate, Architectural Element Courtyard Homes: Useful Layout, Dimensions, and Sociocultural
(Markus, 2016)		Design, Passive Building, Sustainability, Courtyard
(Akbari & Niazi Motlagh Joonaghani, 2021)		Courtyards; Isfahan's Historical Houses; Geometric and Natural Features
(Esperanza Gonza´lez-Redondo, 2021)		Corrala; Timber-Framed Buildings; Malician Houses; Preservation; Stability; Evaluation
(Vedhajanani & Rose, 2016)		Courtyard, Atrium, Homes, Suburban, Conventional
(Luo & Huang, 2022)		"Waterside Cube," Courtyard-Style Buildings, Architectural Culture and Technology
(Dr Donia Zhang et al., 2020)		Courtyard Housing; Courtyard House; Heritage; Social Connectivity; Cultural Landscape; Sustainability.
(M.A. Hind Faraj Bin Tahir et al., 2022)		Conventional Architecture, Modern Style, and Patio
(Leng et al., 2020)		Simulations; Airborne Disease Control and Infection Risk; Courtyard Environment Design
(Diz-Mellado et al., 2021)	Parameter study and simulation analysis to evaluate the qualitative and quantitative data.	Climate Resilience, Courtyards, PET Comfort Data Interpretation, Microclimate Adaptive Thermal Comfort
(Sánchez de la Flor et al., 2021)		Constructing Performance Simulation Modeling Building Energy (BEM) Tools for Simulating Passive Cooling and Energy Demand in Building Inner Courtyards
(Omar Al-Hafith et al., 2017)		Baghdad; Courtyard Pattern; Simulation Software; Designbuilder

(Tabadkani et al., 2022)		Deep Learning Neural Network, Parametric Design, Courtyard Microclimate, Occupant Comfort, Building Energy Consumption, Residential
(Al-Hafith et al., 2017)		Baghdad; Courtyard; Simulation; Shading; Lightup Analytics.
(Mezerdi et al., 2022)		Courtyard House, Hot and Dry Climate, Perception, and Occupant Satisfaction
(Guedouh Marouane Samir et al., 2018)		Building Types; Arid Zone; Simulation; Daylight; Indoor Space
(Shanmugga Rani et al., 2019)		Temperature Comfort, Shadow Pattern, Courtyard Geometry, and Climate
(Al-Masri & Abu-Hijleh, 2012)		Thermal analysis, solar shading, daylighting, and airflow patterns in a computer simulation (IEC 6.0),
(Seung-Young Kim,2001)		Courtyard Structures; Parametric Evaluations; Courtyard Accommodations; Energy-Aware Customs.
(Abdallah et al., 2019)		University buildings, courtyards, thermal performance, sky view factors, and height/width ratio are all related to thermal comfort.
(Al-Hafith et al., 2019)		The geometry of the courtyards, the mean radiant temperature (Mrt), the globe temperature (Tg), the Envi-Met and Ies-Ve simulation tools, and more.
(Ferrari, 2022)		Wind speed, or Envi-Met, is often known as ventilation.
(Ali Karbasforoushha et al., 2023)		The central courtyard, mean interior temperature, semi-hot air climate, and hydrodynamic behavior Kashan
(R. Paul Rogers,1999)		Courtyard Geometry, Courtyard's Geometric Parameters, incoming Short-Wave Radiation, Outgoing Long-Wave Radiation And Wind Shelter.Methods of Physical and Numerical Simulation
(M. Gabriela Toris-Guitron et al., 2022)		Warm and muggy weather, thermal efficiency, comfort, and traditional courtyard homes
(Ragab, 2023)		Energy efficiency, surface albedo, courtyard envelope, and window-to-wall ratio Wwr.
(Bougdah, 2016)	Evaluate the qualitative	Environmental Performance, Cultural Relevance, Courtyard House, Urban Development, Typology, Traditional Architecture, and Sustainable Development
(Ar. Gaurav Gangwar et al., 2016)	Parameter study, literature overview, methodology and case studies, and analysis to evaluate the qualitative and quantitative data.	Wada, Haveli, Socio-Cultural Aspect, Aesthetic Aspect, Cultural Aspect, and Regional Variation.
(Swasti Sthapak et al., 2019)		Courtyard Houses, Traditional Residences, Bioclimatic Significance
Mahmoud Elwerfalli (A Thesis)		Courtyard House, Vernacular, Contemporary, Sustainable Architecture
(Omar Al-Hafith et al., 2018)	Variables, testing, and simulation to evaluate the qualitative and quantitative data.	Baghdad, courtyard pattern, thermal comfort, and efficiency

The main focus of the journals chosen is to comprehend the attributes and research methods with their key parameters
Source: Journals, books and internet sources

4. Literature Overview

Courtyard housing designs originally consisted of rectangular, square, and circle shapes; however, these have been adapted to accommodate ecological factors like site limitations, topography, building orientation, and function. New forms have been created, such as U, L, T, V, H, or Y shapes. The scale and size of the courtyard can be adjusted from close to extant to nonexistent. Studies on courtyard forms and elements at architectural levels highlight their performance and potential for future design development. Scholars have identified psycho-social, cultural, religious, and economic benefits. [13] Buildings should have rectangular courtyard layouts to shield them from dusty winds and sun radiation. On the other hand, three-side courtyards provide a more comfortable temperature, particularly when ventilation and orientation are considered during the design phase; investigated the use of interior courtyards in high-rise residential structures to create natural ventilation and studied the severe effects of the rectangular form concept in summer and winter across four regions. [13, 14] The chowk functions as the hub for all household activities and is seen as an indispensable part of the house. The courtyard, the only open space in the home, allows for natural light and ventilation. Because of its architecture, it may serve as the home's climate control system. Through their windows, the rooms on the top level have access to the courtyard. These lead to an abundance of natural light and ventilation in these areas.

The chowk serves as a physical link between each space on the ground floor. It also creates a visual connection between the top floor and the lower level. According to the Vastu Purush Mandala, the courtyard is the location of Brahma and a central open area. Hindu mythology claims that this place facilitates connections between its people and the divine and supernatural powers. There is usually a big enough rainwater tank under the chowk, and the nearby veranda serves as its outflow. [15, 16] Usually situated in the center of a home, courtyards improve behavioral and environmental issues. They are available in different sizes, but because of Ahmedabad's environment, larger ones are harder to come by. The ideal size is 5–10 square meters. Courtyards are planned with almost square layouts, and users value all dimensions. Users concur with both design elements since they offer visual links between the street and the ground and upper floors. The purpose of strategically placing courtyards is to connect them with the surrounding areas, enabling everyday activities to flow out into the courtyard from the kitchen, living room, dining room, or drawing room. However, rather than using them for eating, sleeping, or cooking, people still use them for sitting, washing, and drying clothing. Courtyards are not comfortable in the winter or during the monsoon season since they are not built for thermal comfort in the summer. They provide airflow for the entire courtyard so that fans will do so during the hot summer months instead of air conditioners or desert coolers.[17]

To organize data, Microsoft Excel is the program utilized. Each variable had a column of its own, and each row corresponded to a single record (a responder). The data has been gathered and arranged by the author. To ensure that nothing is missing or incorrect, this data has been double-checked against the survey's original questionnaire before being included in the excel sheet. Prior to doing a comprehensive statistical analysis and hypothesis testing, the data points' reliability was assessed. The survey questionnaire technique is a helpful tool for this inquiry. The survey questionnaire was developed using the study paper "User Perception of Courtyard as a Thermal Regulator in Households, Famagusta, Cyprus" by Aisha Kabir Marafa and Halil Zafer Alibaba. [18] Shrubs, trees, and flowering plants are examples of courtyard features that may improve the atmosphere and enhance thermal comfort. The inside courtyard and its surroundings may be kept cool by using water features, misters, and tents, especially in the summertime. [19] According to research conducted on a university campus in Hong Kong, gardens located within courtyards, such as those beside the library, serve particular functions and have distinct patterns and landscape designs. While the courtyard garden encourages social contact amongst the public, the meditation garden is a preferable choice for study spaces. [20] Courtyards are architectural elements that provide homeowners with a sense of seclusion and enclosure, serving as extensions of the kitchen during the day and living rooms at night. They promote group activities, family socialization, and visual seclusion through walled entrances or screens. Courtyards can also be used as places to sleep at night when suitable for outdoor activities.

They have been used for over 5000 years to provide light, heat, cooling, and fresh air in thermally suited residential settings. Courtyards are microclimate modifiers, able to redirect winds, reduce temperatures, and alter humidity levels. Courtyards are ideal for large structures that require natural ventilation, heating, lighting, and cooling. They serve as gathering spots for social interactions and cool air reservoirs, particularly in hot, dry regions. They also collect rainwater and can provide sunshine and circulation for thermal comfort. The climate significantly impacts the dimensions and direction of courtyards, and design should prioritize geometry and finishing materials to ensure thermal comfort. Courtyards can be combined with compact living quarters and shared outdoor areas, promoting outdoor activities for those with mobility problems. They can be divided into public and private areas, with the inner court reserved for family members and the public domain used by guests. Courtyards have both symbolic and theological significance, with Islamic design serving as a screen and an oasis and Indian families referring to them as Brah-masthans. [21] The options for courtyard forms in the twenty-first century have increased thanks to developments in technology and materials science. Depending on the region and culture, courtyard acoustics can differ; certain civilizations can tolerate higher levels of noise

than others. The courtyard's width and length ought to be twice as large as the highest point at which acoustically sound noise control equipment may be installed. The connection between viewing distance and height—angles produced at 45 degrees, 30 degrees, 18 degrees, and 14 degrees—determines the impression of enclosure. D/H ratios vary depending on circumstances, locale, and culture; these ratios should only be used as a general guideline. Enclosures can be compromised by gaps in the walls, abrupt changes in the height of the cornice, and abrupt changes in the level of the façade. For instance, Canadian courtyards have D/H=3 or 4, but Arab courtyards have D/H=1/2 or less. Courtyard houses offer numerous financial benefits, including efficient land use, reduced construction costs, and adaptable interior areas. Better cooling is made possible by the courtyard house's thin walls, which minimize heat absorption or loss. Living arrangements may be made more flexible by changing the functions of each space. Courtyard homes serve a variety of clientele, including young couples, elderly couples, single-parent families, and nuclear families. They may also serve as private areas, making it possible to set up an office outside without interfering with daily activities at home. U-shaped courtyards are suitable for both semi-private and public uses. Poor individuals sometimes cannot afford affordable homes because of high labor, contractor, and development prices.

Many impoverished individuals in developing nations construct courtyard homes, which increases their accessibility to a greater number of slum dwellers. [22] A person's fundamental necessities must be met by housing, but the demands and choices of the residents determine the spaces inside it. Local architecture, also known as vernacular architecture, emphasizes geographical elements such as weather, climate, and professions, which have a significant influence on the psychological well-being of the population. The size of the courtyard and the sun's position in the sky both have an impact on the interior surface shade; the courtyard's architecture may also have an impact. Understanding the psychological impact that living places have on inhabitants and their experiences requires an understanding of the courtyard. [23] Variables and parameters are often misunderstood terms in fields like mathematics and physics. Variables are entities that change in a system while parameters connect them.

They are crucial in fields like mathematics, physics, statistics, and analysis. There are two main categories of variables in experiments: independent and dependent. Independent variables are unchangeable or changed, while dependent variables rely on the independent variable. Variables can be discrete or continuous, and their number is important in fields like mathematics and statistics. The number of variables is also important in differential equations and optimization. A parameter, which may or may not have the same dimensions as the variables, is an object that connects or unifies two or more variables in an equation. Fewer parameters can represent a system with several variables, and the same set of variables can have distinct parameters. [24] Variables are quantities which vary from individual to individual. Parameters, on the other hand, pertain to values defining a theoretical model rather than real measurements or qualities.[25] This in-depth examination of the courtyard enables a comprehensive understanding of its dimensions and variables as well as the capacity to assess them in a number of ways. The literature review leads us to the conclusion that the courtyard is an essential component that consists of various aspects. Although the courtyard's characteristics and specifications vary widely, grouping them according to aspects, parameters, and variables forms a fundamental framework for creating a courtyard. For this reason, this template was created with the aid of an adjacency matrix, which helps in determining the degree to which each aspect impacts the other.

5. Research Questions

A thorough analysis of the courtyard and its features leads to the question of how these parameters and variables could be related to various courtyard elements and how to determine the degree of influence towards each parameter and variable. How do various factors, parameters, and aspects function in an adjacency matrix, and how can the effects in a real-world case study be examined using that developed matrix?

6. Materials and Method

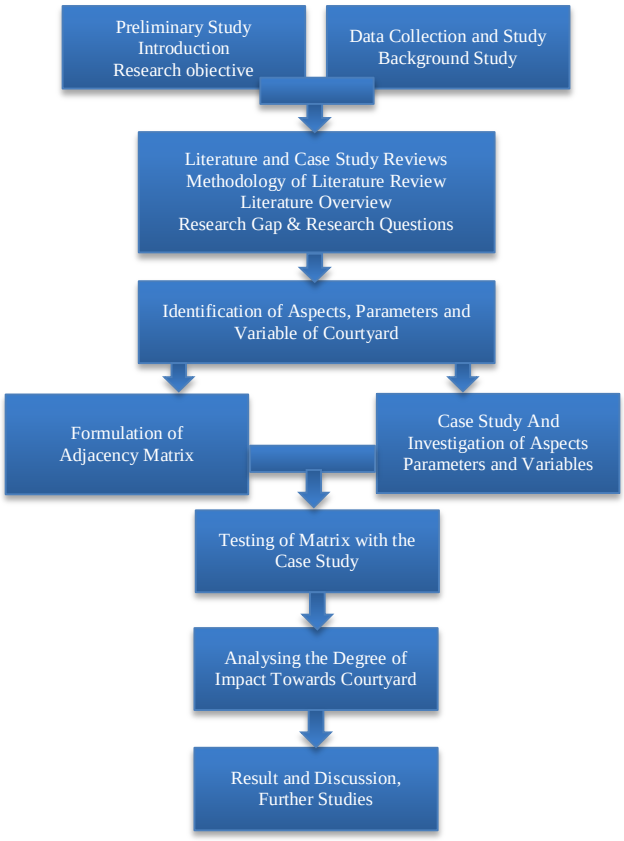


Fig. 1 Flowchart of research

7. Identification of Aspects of the Courtyard

Courtyards are a historically significant vernacular element that has been converted and modified into various architectural building styles, ranging from traditional architecture to contemporary architecture. The first step in this paper is to determine the main and major aspects or characteristics associated with courtyards, which are influenced by a variety of parameters and variables. In this case, the identification is done through an extensive literature review covering the paper's objectives. The results show that there are four main aspects of courtyards: environmental, architectural, social, and economic. Each of these aspects is influenced by a number of parameters, each of which consists of various variables that may change the impact towards the courtyard.

7.1. Aspects of a Courtyard

Based on the influence and result of a space, various dimensions are assigned to these spaces. In the same way, the courtyard exhibits these distinct characteristics and has a few major attributes which establish aspects of the inhabitants and surroundings; consequently, there are four main categories for the courtyard's features.

- Environmental Aspects
- Architectural Aspects
- Social Aspects
- Economic Aspects

8. Identification of Parameters of the Courtyard

An object that links variables is called a parameter. These parameters are found through a literature review of the journals mentioned above, as they are not connected to actual measurements or attributes but rather to factors establishing a theoretical model in terms of courtyards. The following are the courtyard's parameters as determined by this analysis:

8.1. Parameters of the Courtyard for Environmental Aspects

The environmental elements are entirely reliant on the interaction between the courtyard and the other external forces that impact this specific place. Thus, the environmental characteristics have been divided into four major categories: temperature, thermal comfort, ventilation, and daylight. Figure 2 depicts the environmental features of the courtyard.

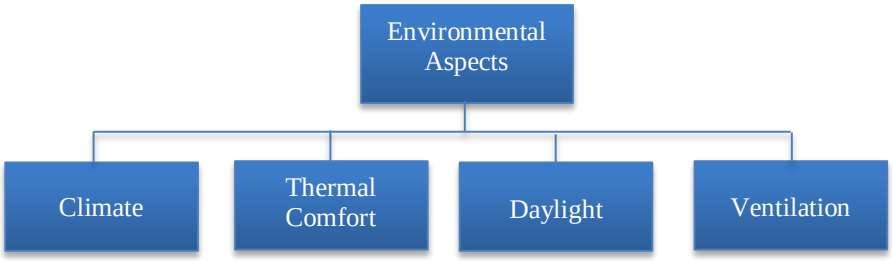


Fig. 2 Parameters of environmental aspect

Source: Author

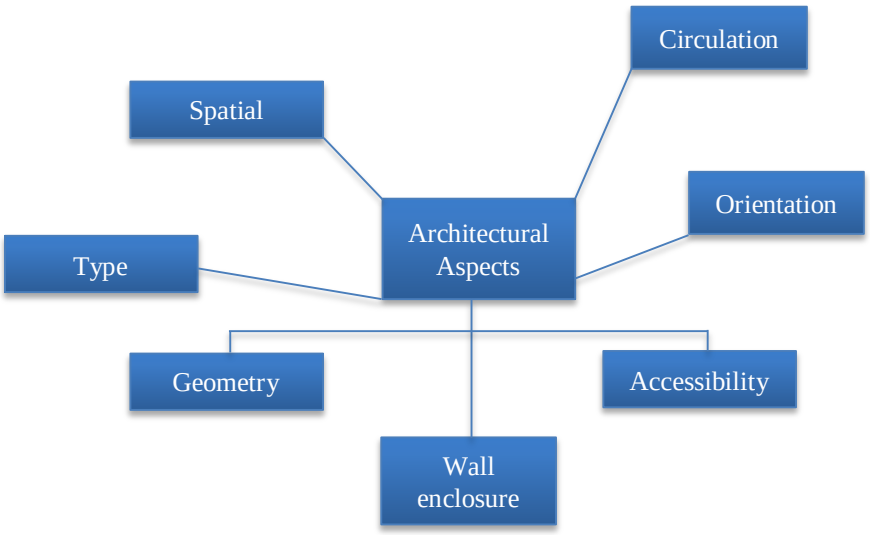


Fig. 3 Parameters of architectural aspect

Source: Author

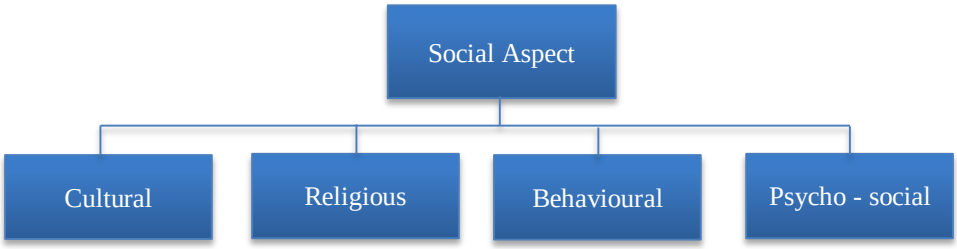


Fig. 4 Parameters of social aspect

Source: Author

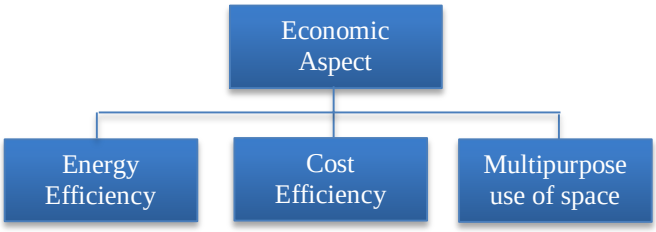


Fig. 5 Parameters of economic aspect

Source: Author

8.2. Parameters of the Courtyard for Architectural Aspects

Geometry, finishing materials, and building plan orientation are all architectural factors that affect microclimate through sun location, shadow, and wind direction. The courtyard's response to the architectural constraints is the focal point of the architectural characteristics. The study found the following factors that determine architectural features: type, geometry, space, orientation, wall enclosure, natural elements, accessibility, and circulation. Figure 3 displays the courtyard's architectural component.

8.3. Parameters of the Courtyard for Social Aspects

In India, courtyard homes are intended to encourage street interaction, with platforms next to entrance doors where visitors can sit before entering the outside courtyard. Inner courtyards have fewer perforations and are intended for women, with vendors permitted to sell female-related items. The social aspects are around how the courtyard reacts to the social variables. The study identified four factors that determine social aspects: cultural, religious, behavioral, and psycho-social. Figure 4 displays the courtyard's social component dimensions.

8.4. Parameters of the Courtyard for Economic Aspects

Courtyard homes feature a number of financial advantages, including efficient site utilization, cheaper construction costs, and adjustable interior spaces. The decrease of walls in courtyard dwellings leads to fewer areas where heat may be gained or lost, lowering the cooling load within the dwelling. The courtyard's response towards many economic factors is the main source of the economic challenges. The study discovered three features that impact economic aspects: energy efficiency, cost efficiency, and multifunctional use of space. Figure 5 shows the boundaries of the courtyard's economic side.

9. Identification of Variables of Courtyard

A variable differs from parameters in that it is an entity that may be changed with respect to another entity; it is also a number that changes from person to person. The variables that impact the selected parameters have been investigated and classed as various variables. On the basis of each aspect, the variables are classified as follows (Table 2, 3, 4, and 5).

9.1. Variables of Architectural Aspects

The variables that impact the courtyard's parameter are recognized and examined in the subsequent Table 2.

Table 2. Variables of architectural aspect

Aspects	Parameter	Variables
Architectural Aspects	Type	Shape, Size, Length, Width, Height.
	Geometry	Shape, Planning, Volume, Enclosure, Openings, Form.
	Spatial	Shape, Size, Length, Width, Connectivity, Zoning, Planning.
	Orientation	Direction, North Facing, South Facing, Openings, Enclosure.
	Wall Enclosure	Shape, Size, No of openings, Material.
	Natural Elements	Type of element, Use, Materials.
	Accessibility	Space, Connectivity, Orientation, Placement Planning, Zoning.
	Circulation	Connectivity, Feasibility, Access, Locus, Mobility, Zoning, Planning.

Source: Author

Table 3. Variables of environmental aspect

Aspects	Parameter	Variables
Environmental Aspects	Climate	Region, Temperature, Humidity, Rainfall, Cloud cover, Wind Speed.
	Thermal comfort	Region, Sun path, Thermal performance, Materials, Courtyard Geometry, Aspect ratio, Surface area to volume ratio, Solar access and shading, The solar shadow index, Thermal mass, Temperature generated pressure difference.
	Daylight	Region, Sun path, Exposure to sun, Orientation, Openings, Enclosure.
	Ventilation	Region, Orientation, Openings, Enclosure, Wind speed, Air velocity, Temperature generated pressure difference, Wind generated pressure difference.

Source: Author

9.2. Variables of Environmental Aspects

The variables that impact the parameter courtyard's parameter are recognized and examined in the subsequent Table 3.

9.3. Variables of Social Aspects

The variables that impact the courtyard's parameter are recognized and examined in the subsequent Table 4.

9.4. Variables of Economic Aspects

The variables that impact the courtyard's parameter are recognized and examined in the subsequent Table 5.

10. Analysing the Degree of Influence Towards the Courtyard

After the literature was studied, the attributes and variables of the courtyard were determined. These are now arranged in the form of a matrix to facilitate comprehension. This tabular matrix can serve as a crucial reference guide for more study and examination of the courtyard. The adjacency matrix is utilized to figure out the degree to which every variable and parameter affects every aspect. Adjacency matrices are often used in architecture to investigate spatial connectedness and linkages. To ascertain the link between parameters and variables, this study uses a matrix. The matrix contains variables that impact with a "1" and variables that have no effect with a "0".

Table 4. Variables of social aspect

Aspects	Parameter	Variables
Social aspects	Cultural	Location, Region, Practice, Occupants, No.of courts, Public courts and private courts.
	Religious	Location, Region, Practice, Occupants/users, Use of space, Symbolism, Myth.
	Behavioural	Location, Region, Practice Occupants/users, Use of space, Activity.
	Psycho- social	Psychological inputs, Occupants, Uses, Influence, Combination of other three parameters, Degree of privacy, Enclosure, Visual connectivity, acoustical privacy.

Source: Author

Table 5. Variables of economic aspect

Aspects	Parameter	Variables
Economic aspects	Energy efficiency	Stack effect, Natural ventilation, Heating and cooling by passive means, Natural lighting
	Cost efficiency	Type, Form, Energy audit, Efficiency calculations
	Multipurpose use of space	Form, Aspect ratio Elements, Activity, function

Source: Author

Table 6. Adjacency matrix for parameters and variables

	TYPE	GEOMETRY	SPATIAL	ORIENTATION	URAL ELEMENTS	ACCESSIBILITY	ALL-ENCLOSURE	CIRCULATION		CLIMATE	THERMAL COMFORT	DAYLIGHT	VENTILATION		CULTURAL	RELIGIOUS	BEHAVIORAL	PSYCHO-SOCIAL		ENERGY EFFICIENCY	COST EFFICIENCY	MULTIPURPOSE SPACE
Shape	1	1	1	0	0	1	1	0	Region	1	1	1	1	Location	1	1	1	1	Stack effect	1	0	0
Size	1	1	1	0	0	0	1	0	Temperature	1	0	0	0	Region	1	1	1	0	Natural ventilation	1	0	0
Length	1	1	1	0	0	0	0	0	Humidity	1	0	0	0	Practice	1	1	1	0	Passive heating and cooling	1	0	0
Width	1	1	1	0	0	0	0	0	Rainfall	1	0	0	0	Occupants	1	1	1	1	Natural lighting	1	0	0
Height		1	0	0	0	0	0	0	Cloud cover	1	0	0	0	No.of courts	1	0	0	0	Type	0	1	0
Planning	0	1	1	0	0	1	0	1	Wind Speed	1	0	0	1	Public courts and private courts	1	0	0	0	Form	0	1	1
Volume	0	1	0	0	0	0	0	0	Sun path	0	1	1	0	Use of space	0	1	1	1	Energy audit	0	1	0
Enclosure	0	1	0	1	0	0	0	0	Thermal performance	0	1	0	0	Symbolism	0	1	0	0	Efficiency calculations	0	1	0
Openings	0		0	1	0	0	0	0	Materials	0	1	0	0	Myth	0	1	0	0	Aspect ratio	0	0	1
Form	0	1	0	0	0	0	0	0	Courtyard Geometry	0	1	0	0	Activity	0	0	1	0	Elements	0	0	1
Connectivity	0	0	1	0	0	1	0	1	Aspect ratio	0	1	0	0	Psychological inputs	0	0	0	1	Activity	0	0	1
Zoning	0	0	1	0	0	0	0	0	Surface area to volume ratio	0	1	0	0	Influence	0	0	0	1	function	0	0	1
Direction	0	0	0	1	0	0	0	0	Solar access & Shading	0	1	0	0	Combination of other three parameters	0	0	0	1				
North Facing	0	0	0	1	0	0	0	0	The solar shadow index	0	1	0	0	Degree of privacy	0	0	0	1				
South Facing	0	0	0	1	0	0	0	0	Thermal mass	0	1	0	0	Enclosure	0	0	0	1				
No of openings	0	0	0	0	0	0	1	0	Temperature generated pressure difference	0	1	0	1	Visual connectivity	0	0	0	1				
Material	0	0	0	0	1	0	1	0	Exposure to sun	0	1	1	0	Acoustical privacy	0	0	0	1				
Type of element	0	0	0	0	1	0	0	0	Openings	0	1	1	1									
Use	0	0	0	0	1	0	0	0	Enclosure	0	0	1	1									
Orientation	0	0	0	0	0	1	0	0	Orientation	0	0	1	1									
Placement	0	0	0	0	0	1	0	0	Air velocity	0	0	0	1									
Zoning	0	0	0	0	0	1	0	1	Wind generated pressure difference	0	0	0	1									
Feasibility	0	0	0	0	0	0	0	1														
Access	0	0	0	0	0	0	0	1														
Locus	0	0	0	0	0	0	0	1														
Mobility	0	0	0	0	0	0	0	1														

Source: Author

10.1. Degree of Impact of Architectural Aspects

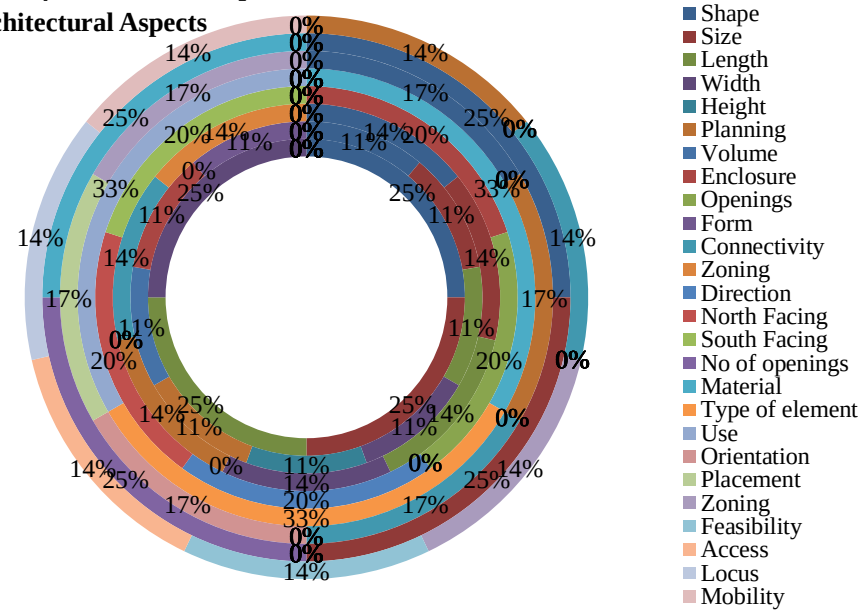


Fig. 6 Parameters of economic aspect

Source: Author (generated using data of adjacency matrix)

10.2. Degree of Impact of Environmental Aspects

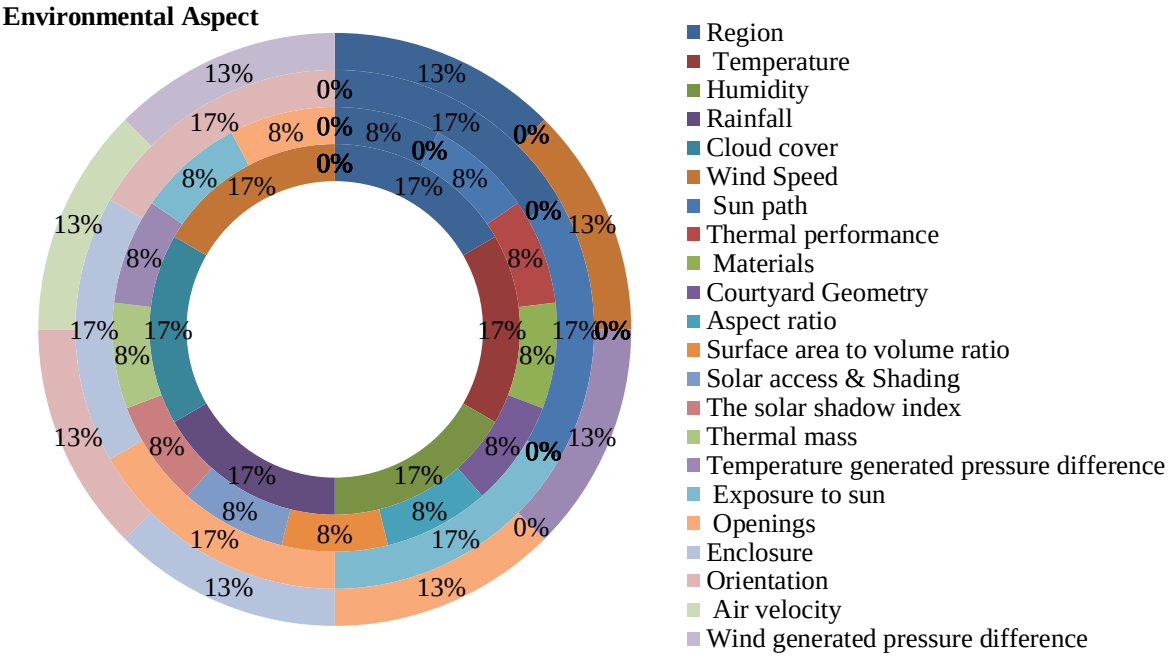


Fig. 7 Parameters of economic aspect

Source: Author (generated using data of adjacency matrix)

10.3. Degree of Impact of Social Aspects

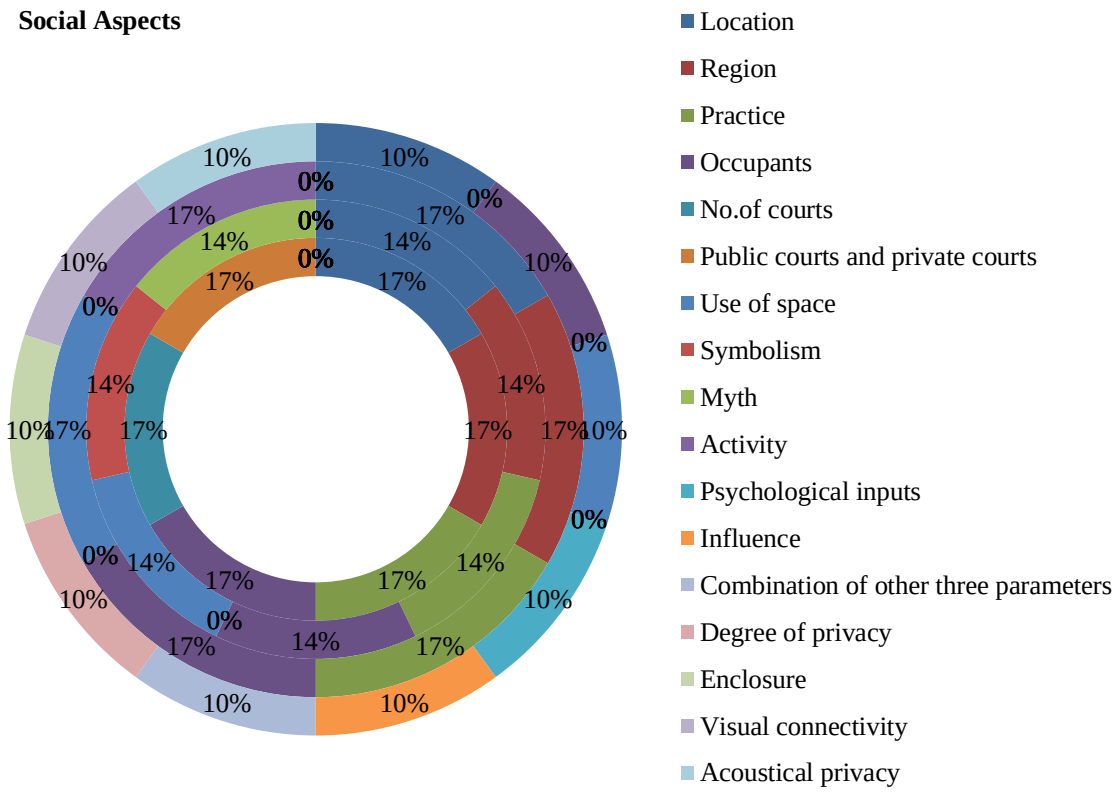


Fig. 8 Parameters of economic aspect

Source: Author (generated using data of adjacency matrix)

10.4. Degree of Impact of Economic Aspects

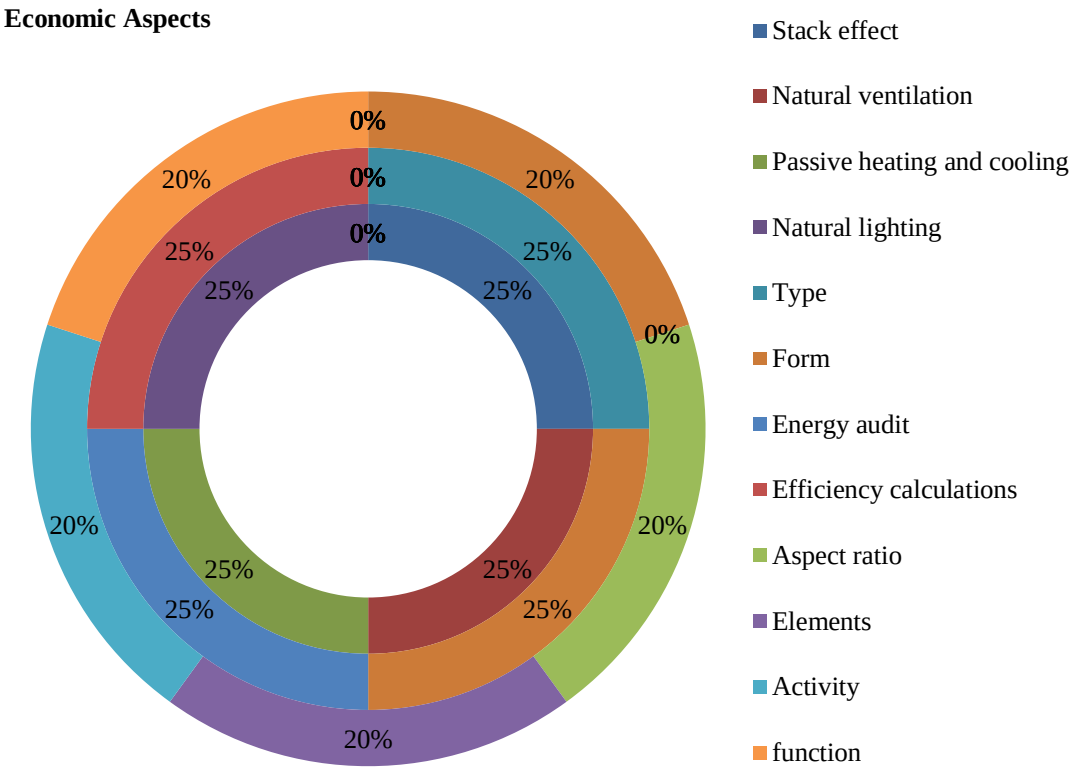


Fig. 9 Parameters of Economic aspect

Source: Author (generated using data of adjacency matrix)

11. Degree of Impact Towards the Courtyard

The fundamental architectural elements of a courtyard are its size, shape, length, width, planning, connection, material, zoning, enclosure, and opening, according to a review of the literature and information analysis. Region, apertures, wind speed, solar route, temperature-induced pressure, exposure, enclosure, and orientation primarily control the environmental component. Location, location, practice, residents, space usage, and activity are all factors that impact social features. Form, stack effect, passive thermal comfort, and energy calculations each affect the economic aspect. The criteria stated above are the most crucial conditions for having a significant impact. Testing this method with an instance study will reveal the specific parameters required for courtyard design.

12. Testing of a Matrix with a Case Study

Description: The study focuses upon the vernacular architectural style of Tamil Nadu's Chettinad House and, on a case study basis evaluates courtyard parameters in a residential building at Kunnarampatti, Madurai district.

12.1. Method of Case Study

The instance analysis was organized such that a research group of ten volunteers was selected to complete a 15-day field inquiry. The observation was completed in fifteen days, which corresponded to the matrix of adjacency created during the first part of the study.

Fig. 10 G+1 house (case study)

Source: Author

Table 7. Details of case study

House Details	
Case Study	House -1
Location	Madurai
Climate	Warm humid
Orientation	E. W
Age	97
Building Type	Residential
Plot Area	450
Total Built Area	380
Building Volume	564
NO. Of Floors	G+1
Floor to Floor Height	3.38
Occupancy (hr)	24
Wall	Brick Work
11 finish	Paint over Putty
Ceiling	Lime concrete
Flooring	Cement Flooring
Window	Wooden frame With a double shutter and Double Panel
Glazing	Yes
Courtyard shape	Rectangular
Courtyard Placement	Central Open
Courtyard Length (L)	6
Courtyard Width (W)	2
Average Height (H)	3.38
Population of house	18

Source: Author

12.2. Case Study

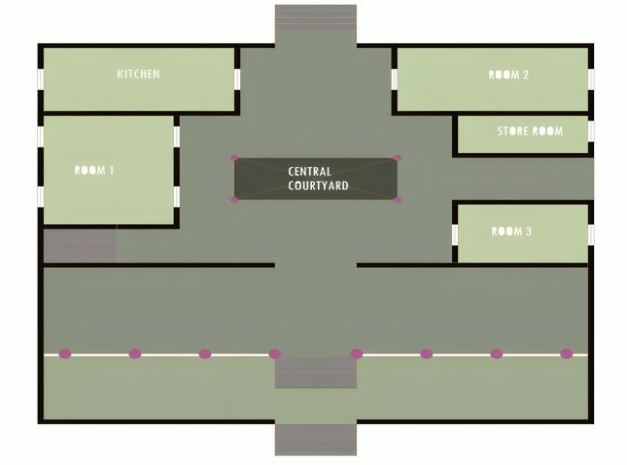


Fig. 11 Ground floor (case study)

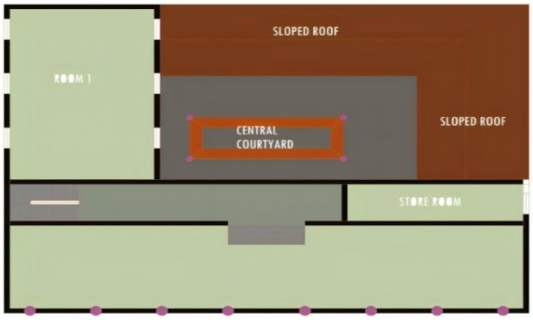


Fig. 12 First floor (case study)

Source: Author

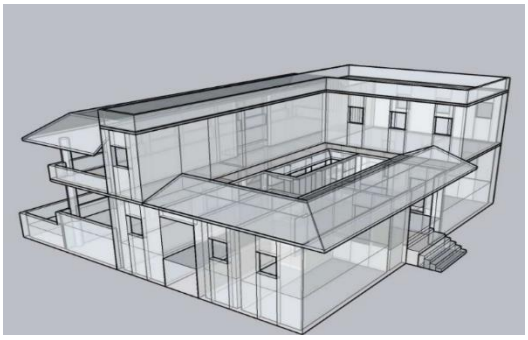
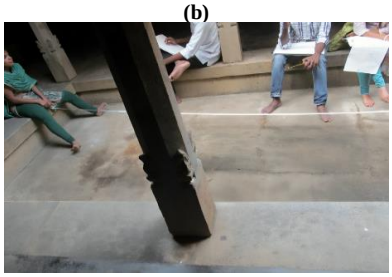


Fig. 13 3D model of selected case house

Source: Author

(a)

(b)



(c)

Fig. 14 (a), (b), and (c) Courtyard and live field investigation.

Source: Author

12.3. Testing of a Matrix with Case Study

Table 8. Adjacency matrix for testing parameters and variables

Architectural Aspects	Type	Geometry	Spatial	Orientation	Natural Elements	Accessibility	Wallenclosure	Circulation
Shape	1	1	1	0	0	1	1	0
Size	1	1	1	0	0	0	1	0
Length	1	1	1	0	0	0	0	0
Width	1	1	1	0	0	0	0	0
Height	1	1	0	0	0	0	0	0
Planning	0	1	1	1	0	1	1	1
Volume	0	1	0	0	0	0	0	0
Enclosure	0	1	0	1	1	1	1	0
Openings	0	1	0	1	0	0	0	0
Form	0	1	0	0	0	0	0	0
Connecti vity	0	0	1	0	0	1	0	1
Zoning	0	0	1	0	0	1	1	1
Direction	0	0	0	1	0	0	0	0
North Facing	0	0	0	1	0	0	0	0
South Facing	0	0	0	1	0	0	0	0
No of openings	0	0	0	0	0	0	1	0
Material	0	0	0	0	1	0	1	0
Type of element	0	0	0	0	1	0	0	0
Use	0	0	0	0	1	0	0	0
Orientati on	0	0	0	0	0	1	0	0
Placemen t	0	0	0	0	0	1	0	0
Feasibilit y	0	0	0	0	0	0	0	1
Access	0	0	0	0	0	0	0	1
Locus	0	0	0	0	0	0	0	1
Mobility	0	0	0	0	0	0	0	1

Environmental Aspects	Climate	Thermal Comfort	Daylight	Ventilation
Region	1	1	1	1
Temperature	1	0	1	0
Humidity	1	0	0	0
Rainfall	1	0	0	0
Cloud cover	1	0	0	0
Wind Speed	1	0	0	1
Sun path	0	1	1	0
Thermal performance	0	1	0	0
Materials	0	1	0	0
Courtyard Geometry	0	1	1	1
Aspect ratio	0	1	0	0
Surface area to volume ratio	0	1	0	0
Solar access and Shading	0	1	0	0
The solar shadow index	0	1	0	0
Thermal mass	0	1	0	0
Temperature - generated pressure difference	0	1	0	1
Exposure to sun	0	1	1	0
Openings	0	1	1	1
Enclosure	0	0	1	1
Orientation	0	0	1	1
Air velocity	0	0	0	1
Wind-generated pressure difference	0	0	0	1

Source: Author

The matrix illustrates the relationship between variables and parameters depending on architectural features. The matrix shows that the geometry significantly influences the courtyard's architectural aspect in the parameter and the planning in the courtyard variable. The two most important architectural elements are space and circulation. In terms of variables, architectural design relies heavily on shape, enclosure, and zoning. The other architectural aspects and variables reinforce the courtyard's architectural identity. The environmental component is essential to the courtyard's operation since environmental factors have a strong impact on other components. In light of the matrix, the most fundamental is thermal performance, which is an important environmentally supportive measure. Counters supporting this aspect of region, geometry, and apertures are essential environmental elements to take into account. The second most affected characteristic is ventilation. The following settings and variables function as supporting parameters and variables, so boosting the courtyard's environmental performance.

Table 9. Adjacency matrix for testing parameters and variables

Social Aspects	Cultural	Religious	Behavioral	Psycho - Social	Economic Aspects	Energy Efficiency	Cost Efficiency	Multipurpose Use of Space
Location	1	1	1	1	Stack effect	1	0	0
Region	1	1	1	0	Natural ventilation	1	0	0
Practice	1	1	1	1	Passive heating and cooling	1	0	0
Occupants	1	1	1	1	Natural lighting	1	0	0
No.of courts	1	0	0	0	Type	0	1	0
Public courts and private courts	1	0	0	0	Form	0	1	1
Use of space	0	1	1	1	Energy audit	0	1	0
Symbolism	0	1	0	0	Efficiency calculations	0	1	0
Myth	0	1	0	0	Aspect ratio	0	0	1
Activity	0	0	1	0	Elements	0	0	1
Psychological inputs	0	0	0	1	Activity	0	0	1
Influence	0	0	1	1	function	0	0	1
Combination of the other three parameters	0	0	1	1				
Degree of privacy	0	0	0	1				
Enclosure	0	0	0	1				
Visual connectivity	0	0	1	1				
Acoustical privacy	0	0	1	1				

Source: Author

The social aspect is considered to be the most crucial aspect influencing many measures. The psychological and behavioral features are considered the two most important factors in preserving the space's vibrancy. Regarding social support, the three most significant courtyard characteristics are its location, practice, and inhabitants. The social component is according to the interaction of the courtyard with its users all day long and year. Cultural and religious boundaries shift with time, causing occasional effects on space. The region and application of space are two more elements that impact the social qualities, while the other variable supports the courtyard's social component. The economic aspect is entirely reliant on the effects of space on economic feasibility. Parameter's primary focus is energy efficiency and space utilization since they serve as a passive energy tool in the residential unit. The function, activity, and other criteria serve as supporting variables within the framework of economic viability. Incorporating a courtyard in a building improves lighting and ventilation while also inducing comfort and seclusion, resulting in a secular place for the occupants.

13. Result

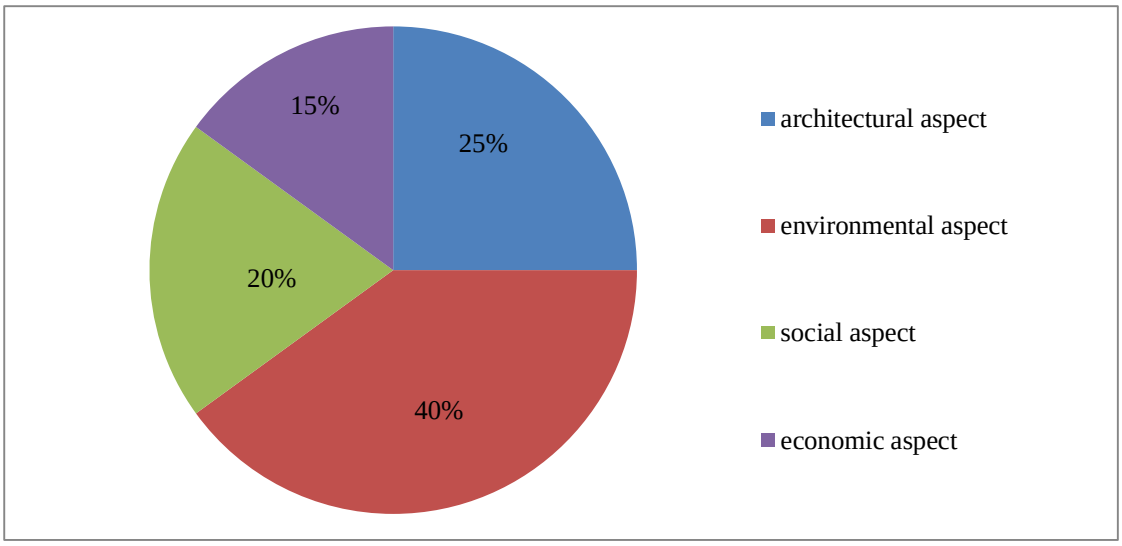


Fig. 15 Aspects of the courtyard

Source: Author (generated using data of adjacency matrix)

History has shown that Examining the courtyard is crucial, and the decision to focus on this particular area of study helped to establish the parameters for its comprehension. This study created an ideology by examining the courtyard's elements. Understanding the courtyard's features, which are influenced by a variety of factors, is the main goal of the research. The first segment of the inquiry, which began with a literature review, gave us a basic understanding of the courtyard's features with respect to its input parameters. Analyzing the space involves determining the degree of impact within the courtyard. The arriving data is created as a model of an adjacency matrix, which is commonly utilized in architecture as part of feasibility research. The generated matrix serves as a grading factors for the courtyard's overall efficiency. The constructed matrix is then evaluated using an existing scenario in which a field investigation was conducted with a team of folks, providing us with the necessary data. Test analysis yielded the following results: The courtyard’s environmental element is important in its characteristics since it directly or indirectly impacts the other courtyard's aspects, asking to have their input into the courtyard examined. The architectural and social aspects are almost equally weighted, resulting in equal contributions to the courtyard's characteristics.

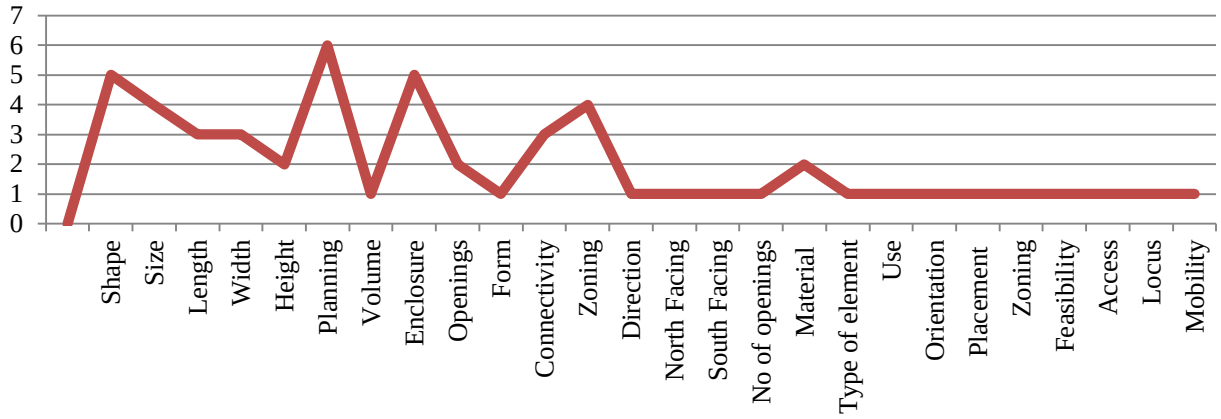


Fig. 16 Relation of architectural aspect

Source: Author (generated using data of adjacency matrix)

In accordance with compatibility between the parameters and variables associated with the architectural aspect, the input of the planning and geometry plays a crucial part in the courtyard's quality since the environmental aspect is dependent on the similar geometry and exposure to sun and opening, creating a comfort zone for the users. Failure to meet these main criteria may result in an unpleasant zone of livelihood. (As seen in Figures 16 and 17)

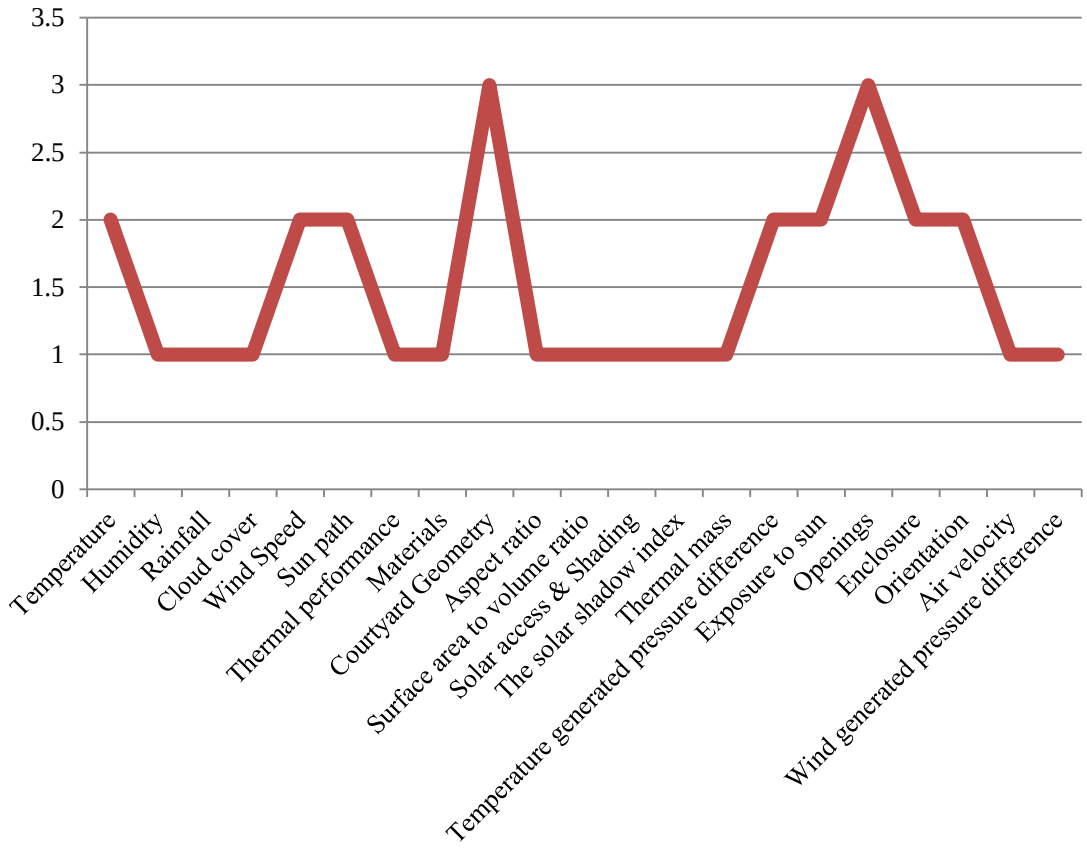


Fig. 17 Relation of environmental aspect

Source: Author (generated using data of adjacency matrix)

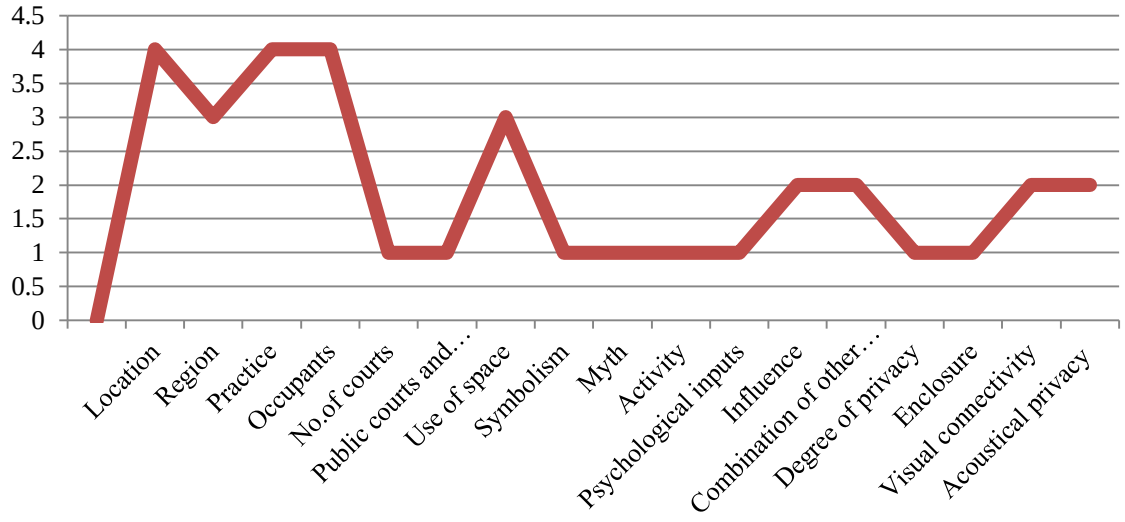


Fig. 18 Relation of Social Aspect

Source: Author (generated using data of adjacency matrix)

The study carried out throughout the investigation's initial phase, which was followed by the testing of a live case, concluded that the social aspect is completely dependent on the changing situations of cultural practice, As the case study makes clear that the behavioral and psycho-social components have a significant influence on the lively hood of space. The time analysis of functionality and activity indicates that the behavioral and psycho-social factors have a stronger impact on the courtyard's social component. In respect to the economic aspect, ventilation and the transmission of daylight provide essential airflow and natural light while also offering energy efficiency through the application of the courtyard, so adding to their economic performance (As seen in Figures 18 and 19).

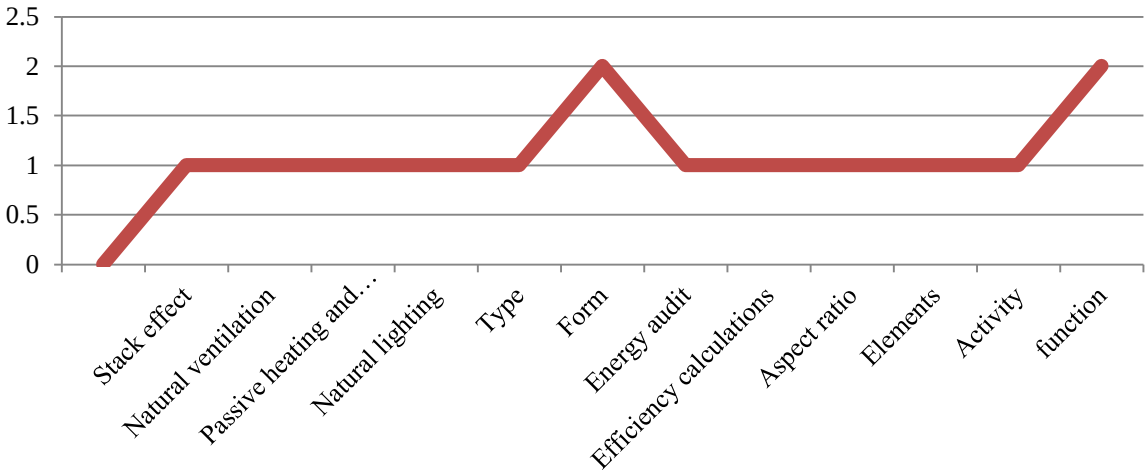


Fig. 19 Relation of Economic aspect

Source: Author (generated using data of adjacency matrix)

14. Conclusion

The background investigation concludes that a thorough examination of the factors and variables of courtyards from numerous perspectives is crucial to the field's research. Through the literature review, we learn that while earlier research has tended to discuss a variety of topics, a comprehensive grasp of the characteristics and factors of courtyards has not been adequately explored. The innovative feature of the research was identifying the parameters, variables, and aspects through a literature review and the usage of an adjacency matrix with a live case study to evaluate the matrix. The paper intended to elucidate the dimensions and

components of the courtyard, as well as to investigate the effects on features of the courtyard. The goal of this study was to comprehend every aspect of the courtyard, including any unobserved factors and variables. Understanding these courtyard qualities is essential for creating an effective courtyard layout.

In context with the results, the environmental component of a courtyard is quite essential. The dimensions and features investigated using the created matrix highlight the significance of geometry, planning, region, climate, and inhabitants as fundamental and crucial aspects to consider for an efficient courtyard design.

Further Studies

The findings may be useful to future scholars studying the essence of courtyards, and the matrix generated might act as a guide for future courtyard elements and designs. The significance of environmental elements motivates continued research in these disciplines additionally to the establishment of a new foundation for upcoming investigations.

Author Contribution Statement

GR (Author) and RS (Corresponding author) conceived and designed the research. GR conducted case studies. GR contributed new reagents. GR and RS analyzed data. GR wrote the manuscript. All authors read and approved the manuscript.

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