Redesigning waste: An exploration into the role of architecture in an integrated solid waste management system

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Abstract

The world is urbanizing at an unprecedented rate with over one-third of the global population currently residing in urban areas and a Fig.ure projected to exceed 50% by 2050. Rapid urbanization has intensified critical challenges, particularly in solid waste management, as global waste generation reaches approximately 2 billion tons annually, with 33% being mismanaged. This mismanagement poses severe threats to human health, ecosystem, and the environment, often causing irreversible damage. Despite the scale of this crisis, architectural solutions remain underutilized in waste management systems. This study delves into this predicament and studies how architecture used efficiently can help form an integrated waste management system, further emphasizing public engagement. Recognizing that awareness is pivotal in waste management, the study proposes a multifunctional waste center incorporating a waste-to-energy plant, a material recovery facility, and most critically accessible public spaces for the general public. By integrating vibrant communal areas, the design aims to demystify waste management processes and foster public participation. Architectural elements such as green roofs, living facades, natural lighting, jalis, and water features are utilized to create an aesthetically harmonious and contemplative environment. The study concludes that architecture's role in waste management extends beyond functionality and it must inspire reflection and shift perceptions, ultimately encouraging sustainable behavior. The proposed waste center serves as a pioneering model, addressing not only waste treatment but also transforming public mindset, thereby fostering a holistic integration of community and process.

Keywords: *Architecture, Bhutan, Garbage, Waste Center, Planned obsolescence, Circular economy*

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1. INTRODUCTION

We are living in the Anthropocene as researchers have documented a new geological epoch (Heymans et al., 2019). Human beings dominate most processes in the planet and have come to stand on the top of the food chain. The defining characteristics of this age is urbanization. The world is urbanizing at a pace never documented before. "In 2015, more than half of the world's population lived in urban areas, and by 2050, it is expected that two-thirds of humanity will call a city home" (UN ,2016). While urbanization is not inherently detrimental, it generates significant adverse consequences including urban sprawl, socioeconomic disparities (poverty and unemployment), inadequate housing and infrastructure provision, and most critically, substantial environmental degradation. (Zhang, 2016). Solid waste is one of the main consequences of urbanization that has a serious adverse effect to the environment. Solid waste is defined as material that no longer has any value to the person who is responsible for it (MoWHS,2011).

The world produces approximately 2.01 billion tons of waste annually with an estimated 33% being improperly managed, posing significant environmental risks (World Bank,2018). Improper waste management have numerous negative consequences for both environment and human population. Key impacts include marine pollution, drainage obstruction leading to flooding, transmitting diseases via vector breeding, wildlife endangerment and affecting economic development, particularly in sectors like tourism.

Bhutan is a small country in South Asia with a population of about 720,000 people. Although small the country is also facing the advent of a waste crisis. As the country moves towards a new age of development and prosperity, consumer trends tend to move toward the production of more biodegradable wastes. The per capita waste generation was seen to be about 0.253 kg per person with urban households producing about 0.7 kg and rural household about 0.5 kgs of waste every day. (NWIS,2019) 428 tons of medical wastes was seen to be produced annually with an annual increase of 15-20%. Commercial establishments produced 2.401 kg/commercial unit while offices produce about 0.207 kg/staff /day (NWIS,2019). Industrial sectors collectively produce an estimated 520 tons of waste material

per annum. (NWIS,2019). In total the country produces about 172 tons of waste daily. Most of which were seen to be produced from residential and commercial establishments. Thimphu, Bhutan's capital city alone generates about 40 tons of waste daily. Illegal and indiscriminate dumping of wastes are seen in open spaces and rivers banks according to Kuensel, the national newspaper. The second largest city Phuentsholing generates 20 tons of solid waste per day. However, 25–50% of this waste is disposed of through illegal dumping, reflecting insufficient public awareness regarding proper waste management practices. As Bhutan moves away from being an Agrarian society, the waste generated shows that non-biodegradable wastes are growing to be the prominent composition. As these collect over time, they don't decompose and hence are more likely to harm the environment.

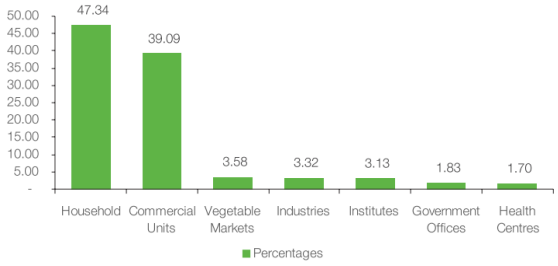


Fig. 1: *Waste produced by different establishments. (Source: NWIS 2019)*

Currently, sanitary landfills serve as the dominant municipal solid waste (MSW) disposal method in Bhutan, receiving approximately 80% of all managed waste. The country relies on this conventional treatment technology, with an estimated 25 operational landfill sites distributed nationwide (Kuensel). In addition, the reports of the World Bank state that, landfill standards in Asia and Africa consistently fall below European and North American benchmarks in both design and operational management (World Bank, 2005). This assessment holds true for Bhutan, where national reports indicate sanitary landfills suffer from inadequate planning and substandard construction (Kuensel). Further, the country's mountainous topography exacerbates these limitations, creating severe land scarcity for proper landfill development (10th FYP).

A fundamental limitation of landfill-dependent waste management systems is their significant methane emissions. This renders them environmentally unsustainable as a primary waste treatment strategy. According to the Environmental Protection Agency of the United States of America, Landfills are the third largest cause of anthropogenic methane production or methane produced by men (EPA,2019).

2. METHODOLOGY

The study will follow a Qualitative method with mostly case studies and literature reviews. The three aspects of the study will include Solid waste management and awareness strategy. Open and transparent architecture for industrial building and the physical aspects of a waste center. The study comprises the four phases seen in Fig. 2.

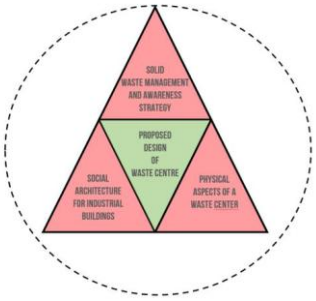


Fig. 2: *Aspects of the project*

Table 1: *Methodology*

The main focus of the research is on the role of architecture in the waste management system. The following questions reflect the general theme of the research.

- What role does architecture play in waste management?
- Why does the nature of industrial architecture be rethought upon?
- Can public spaces be used to connect people to industrial structures and more importantly industrial processes?
- How can we incorporate public spaces in industries to make industries more people friendly?

3. LITERATURE REVIEW

3.1. Concept

In economics and industrial design, planned obsoletion refers to the predetermined disintegration of the design after which it fails to function. Companies usually use planned obsoletion as a means to introduce new products

overtime which means existing products are bound to become wastes over time and it is a planned process. Ironically in the context here however, planned obsolescence will be used here to disintegrate the structure thus it will be used to reduce waste not to generate it. The idea is the disintegration of the function of the structure as a waste treatment plant into a public friendly park and education center.

The main idea behind the waste center was to treat waste and generate awareness without harming the environment. Since public participation was a crucial aspect of the waste center initially the idea was to create a treatment plant which would be connected to the public spaces through open and green spaces but slowly it evolved into a much more integrated form. The gardens and public spaces were integrated into the design of the treatment plants. The ultimate goal in this case was the functional engulfment of the waste to energy plant through time and awareness. It symbolizes the disintegration of the structure to make way for Mother Nature. And true to that the structure integrates the surrounding environment and various other design features into its form.

3.2. Massing and form derivation

The massing was based on the concept of open and transparent architecture. The central space was used as a public plaza. The structure will open unto the public plaza, the north facing facades of the structure will have large windows to promote the interaction of public and process. Landscape here acts as the link between the different components of the waste center. It is not just another component of the waste center but inter twines with all the others and hence act as the spine of the design that supports all the others.

3.3. Public spaces

Safety and functionality of industrial architecture has always been of the highest quality. The social and aesthetic aspect of these structures however are always found to be lacking. This kind of architecture also face severe discrimination as compared to other mainstream forms of architecture as people always looked at it with disdain, due to banality of the mass-produced structures. This has have led to consequences in the perception of industrial architecture and have made most of them uninviting and cold.

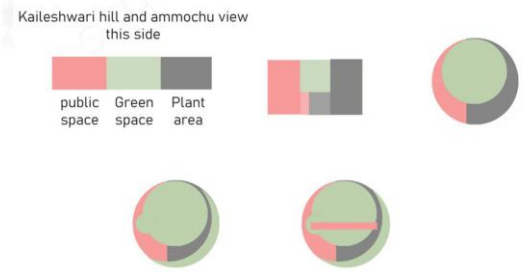


Fig. 3: *Massing of the waste center*

The need for change here occurs in sectors like the waste management system where the interaction of people and the process is crucial. The now closed process has to be an open process which invites people to participate and contribute to the waste management system. For those public spaces that integrates the process and public spaces are necessary. They can contribute to erase negative stereotypes of the industrial architecture and promote people to interact with these processes. These can also lead to wonderful iconic blend of public spaces and industrial architecture.

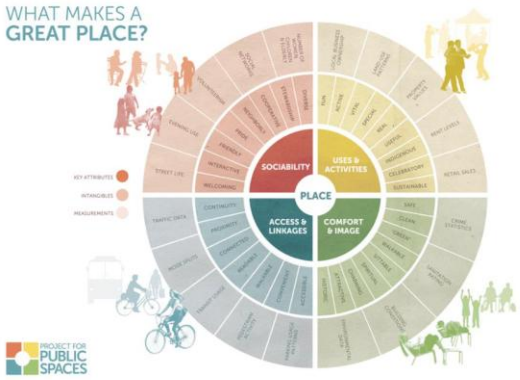


Fig. 4: *What makes a great place? (Soure:PPS)*

Great public places according to the PPS (project for public space) is where celebrations occur, there is exchange in social and economic activities, where people meet and interact and an exchange of culture is noticed. Public places make stages where people can gather and socialize. Researchers in the PPS after evaluating thousands of public spaces around the world have concluded the following four characteristics of a public place that make it successful. They are:

a. Accessibility

This denotes the connection to the surrounding

context. How easily people can arrive and return are key to know how often people will use it. Visually the place should be unobstructed and be visible from a distance and in closer perspective. Access to public transit is also preferable and the edges of the place are important. Interesting features on the edge aside from blank walls are preferred.

b. Comfort and image

The way people perceive the place is an important component of a public space. It is often misjudged how people prefer to have a place to sit. A good image meaning a clean and healthy surrounding combined with safety and places for people to sit make up for a perfect public space.

c. Uses and activities

Activities are the primary reason why people visit public spaces. They decide why people come and why they leave. They could also be the reason people return to the spaces after they visit. Activities can make a public space special and unique. A lack of activities means people hardly ever visit the public space.

d. Sociability

Human beings are social beings who have to constantly interact with others. A public space should promote social interactions and foster them. Although hard to attain if a public space is able to achieve it, it creates bonds and emotions that will inevitably attach to the place itself

3.4. Case studies

a. Copen hill

Reason for Selection: Copen hill is the start of the hedonistic sustainability movement which combines sustainable practices with social and aesthetic appeals.

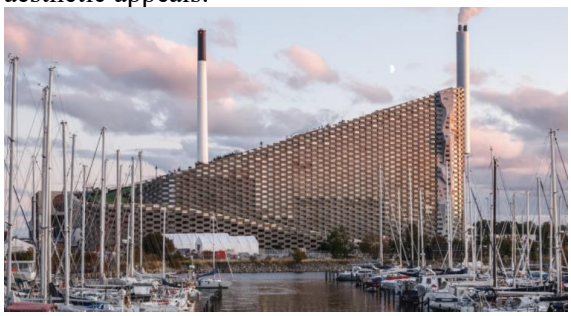


Fig. 5*: Copen hill*

The Amager bakke, also known as the Copen Hill designed by BIG (Bjarke Ingles Group) integrate the latest technologies in waste treatment and energy production making it the cleanest waste to energy plant in the world and connects the community and the environment with the energy plant, turning Amager bakke into urban recreational landmark. The most unique feature of the plant that makes it unique from any other plant in the world is the utilizing of the rooftop to create an artificial mountain slope where people can actually ski from.

b. Bozen Waste to energy plant

Reason for selection: The waste to energy plan has an open system where the general public can be educated and participate in the working of the plant. They also have education rooms and exhibitions which creates awareness. The plant also utilizes sustainable features such as green roofs and green courtyards.

Fig. 6: *Bozen WtE Plant*

The Bozen WtE plant is a power plant located near the entrance of the Italian city of Bolzano. The architects have used the beautiful site and surrounding context to derive the motifs for the form of the structure. It features sustainable roofs and courtyard, lively interiors for the workers and visitors and an open system which incorporates public awareness and education in the waste treatment process.

c. Incineration Line in Roskilde

Reason for selection: This incineration plant incorporates the use of heavy architectural symbolism to bring about the message of change in a historical City. The structure represents the transition into modernity through technology.

Fig. 7: *Incineration line at Rosklide*

The plant is located in an industrial and historical zone at Rosklide, Denmark. It is located on flat landscape surrounded by commercial buildings. The aluminum perforated façade of the plant

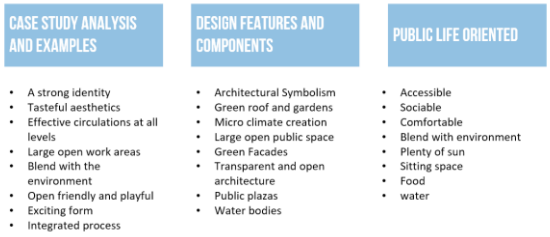
symbolizes the plant's purpose of energy production. The plant function as a glowing beacon for the city. The plant is a step towards a superior hyper modernism in a traditional city representing a gradual movement into the new age of technology.

Other case studies were also done on modern industrial buildings. Modern buildings which include

1. Inotera Headquarters & Production Facility / tec Design Studio
2. Gas Kompressor Station Egtved / C. F. Møller Architects
3. Chayi Industrial Innovation Center / Bio-architecture formosana
4. Bresco WfE *power plant*

These structures were studied to infer qualities and elements of a modern industrial buildings which will be used for the creation of the waste center.

4. INFERENCES



The elements and components of great industrial architecture was derived. Great industrial architecture was shown to have a strong identity that blended with or juxtaposed the surrounding contextual environment. The aesthetics were also seen to be a crucial element and exciting forms could encourage people to visit these structures. Large open areas to work and an open and transparent system that was well circulated and friendly are necessary.

Aside from that element of public design that should be incorporated was also obtained. A good public space should be accessible, sociable comfortable and incorporate social interactions. To make a good public space and to attract more people it was seen that the sun, wind, trees, sitting space, water bodies, and food were a factor.

From these studies various design features and components were also attained. These included architectural symbolism where architecture can be used to spread ideas and spaces could be designed based on that. Green roof, green facades and gardens that create sociable environments and microclimates for the structure. Public plazas with large open spaces can help attract people to make a transparent and open system which will align with the objectives of this study.

Additional studies were also conducted for the design of the waste center which include.

Area programming

The spaces are acquired from the hypothesize and conceptualized from a case study done of the B.R.E.S.C.O power plant. Various architectural standards from Neufert and time savers were used to extract the required areas for the spaces. The main components of the waste center inferred are:

Fig. 8: *Space organogram*

Site analysis

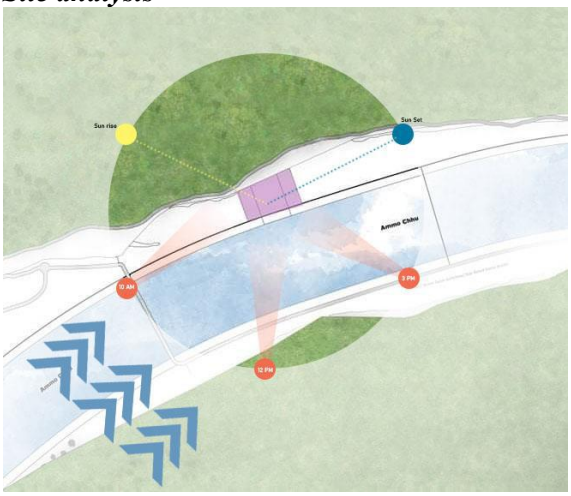


Fig. 9: *Site sun path and wind diagram*

The site selected is on the utility precinct of the UV1 high density mixed used precinct of the Ammochu township development. The township falls under Phuentsholing Thromde, one of Bhutan's four class A thromde under Chukkha dzongkhag. Selection of site for a waste to energy plant is a crucial step towards the success of the project. According to Wu considerations of site selection mainly can be summarized into business operation, government intervention, natural environment, and social influence. The study for the site is done in four main levels; City Level Analysis, Precinct Level Analysis, Site Level Analysis and SWOT Analysis. This will provide the contextual understanding of the site for the design process.

5. APPLICATION

This section focuses on the various analysis and inferences drawn from the earlier sections to design the waste center.

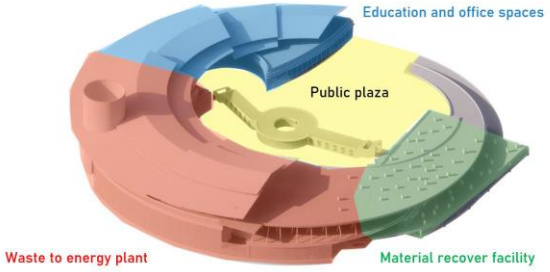


Fig. 10: *Components of the waste center*

5.1. Design Translation

The four main components of the waste center will be

a. Material recovery facility
b. Waste to energy plant
c. Education and office spaces
d. Public Plaza

Fig. 11: *Site plan*

The total site area is 8.02 acres. The structure plinth area is about 2.2 acres with a built-up area of 23195 m2. This means that the structure covers 27.4% of the total site area and has a FAR of 0.69. The entrance of the structure falls on the northern side of the site. Four main entrances have been provided for the structure. This is to differentiate the different traffics of: people, vehicles and waste trucks. Underground basement parking has been provided for both the public and Garbage trucks. The main entrance opens up to a large public plaza which becomes the connecting space for all the other spaces.

5.2. Design Details

The following features and components have been implemented into the design of the waste center. It features a central public plaza for an open and transparent architecture. Green open spaces will be utilized to bind all these together as well as act as a component itself. Circulation of people and waste trucks are differentiated to prevent accidents.

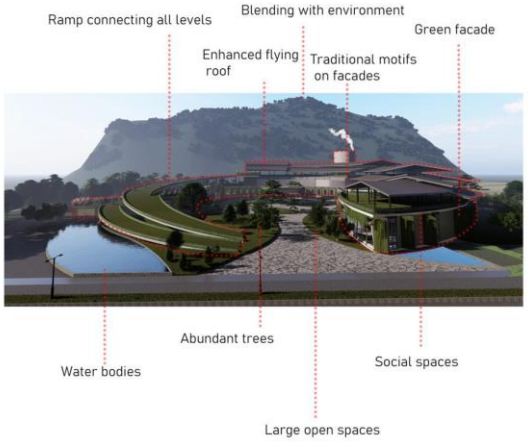


Fig. 12: *Implemented components and elements'*

The structure has a strong identity. Traditional Bhutanese iconography is embossed into the concreate as well as create the patterns of the jail. The roofs are a highly exaggerated version of the Bhutanese flying roof. Aside from that, the most prominent feature of the design is the engulfment of nature. Looking at the structure from a distance reveals the facades shrouded in nature. Landscaping and the structure here become one. These was mainly done to create a micro climate and make the structure aesthetically pleasing. Water bodies and trees are also a big part of the structure. These two feature compliments the structure at every side. The form of the structure also strays away from conventional Bhutanese form, this is done not only to create an exciting and unique form but to accentuate the views of the Kaileshwari hill and take advantage of the wind and sun to its maximum. A circular form encourages open and transparent architecture. The center will also have green roofs which people can access through the large green ramps that connect all levels of the design.

Fig. 13*: Elevation of the waste center*

Fig. 14: *Section though material recovery facility*

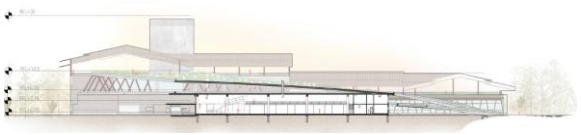


Fig. 15: *Main entrance view*

Fig. 16: *View of Public Plaza*

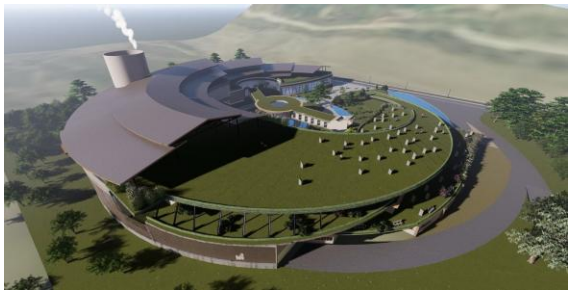


Fig. 17: *View of ramps*

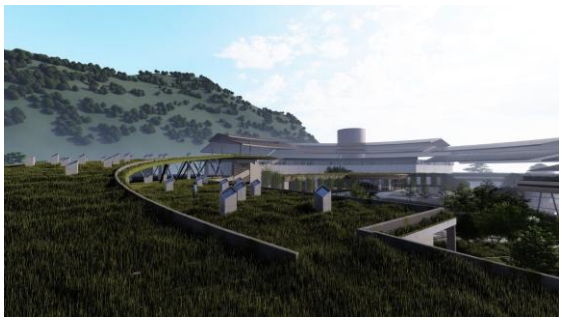


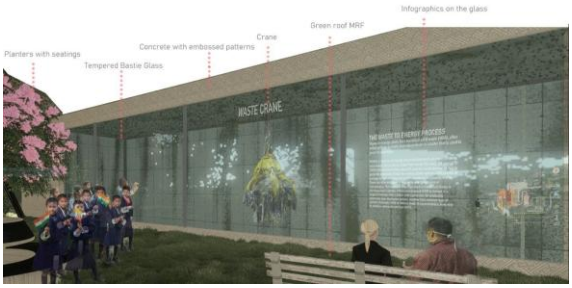
Fig. 18: *View of Green ramps and rooftop gardens*

Fig. 19: View from public entrance

The Phuentsholing waste awareness center will be a facility aimed at the aversion of a waste crisis in Phuentsholing and in Bhutan. It aims not only at treating of the waste in an environmentally friendly processes and generating commercial value for wastes which are considered a nuisance but also at creating awareness about waste and an indoctrination of a new waste culture. This thus fulfils the 3 pillars of sustainability the economic, commercial and social aspects. Hence the project is a part of sustainable development. The center will also be equipped with various education and awareness-oriented spaces. These spaces include

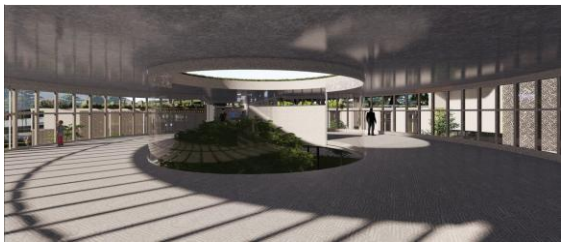
a. Crane theatre

The space acts as a place to relax as well as a place to learn. The people will be able to see the waste crane picking up the waste and the start of the waste to energy process. Infographics about waste management and the process will be printed on the Bastie/tempered glass.



b. Reflection space

The reflecting space is a space floating in the center of the public plaza. Makes use of the open space and abundance of natural light and greeneries to create a deep deflection space in both a metaphorical and real sense. It becomes a reflecting space where people get to know where we are and where we are headed to. It is the focal point of the center and signifies the start of the journey of the waste management in an individual and in the society. It is adorned with waste infographics on the glasses.



c. We are Here room

The we are here room or the waste theater is a room where we get to see the stockpile. It showcases the waste that we produce collectively and is aimed at shocking people. It is expected to create questions in the spectators' mind of where we are and where are headed to with our present waste culture. This room also helps us to have a collective goal that we as a community can align to so that we can reach a targeted goal indicator that will change every year.

Fig.. 20: *Interior of the MRF*

6. CONCLUSION

Waste management is multidisciplinary approach yet a central question guiding this research has been the role of architecture within this system. It appears that architecture's function extends beyond physical infrastructure, instead contributing through the design of meaningful spaces capable of transforming mindsets, perceptions, and, most critically, cultural practices.

While Bhutan is not currently experiencing a full-scale waste crisis, the potential for one loom in the near future. The most pressing concerns are the prevailing waste culture and a general lack of public awareness. Furthermore, existing waste treatment methods remain insufficient, resulting in mismanagement that poses significant risks to the environment. Hence, the proposed Waste Center in the new Ammochu Township Development site serves as a pilot project where the three aspects of Environment, Commercial and Social are integrated into the design and forms a holistic development framework. In addition, the project is also designed to raise public awareness and shift perceptions surrounding waste-challenging conventional stereotypes.

Currently, waste treatment and management operate as a closed system. From the public perspective, the process ends once waste is discarded into collection trucks, obscuring the subsequent critical stages of handling and processing. However, an effective integrated waste management system requires openness and transparency, qualities that architecture can actively facilitate. Research indicates that public indifference toward waste management is partly rooted in the design of industrial facilities. Conventional industrial architecture prioritizes functionality and safety over social and aesthetic engagement. To foster public participation, strategies such as vibrant public parks, transparent design elements, and visually engaging structures have proven effective in demystifying industrial processes. By integrating these features, the proposed facility can serve as both a functional plant and an educational platform.

This study purposes that architecture's role in waste management extends beyond physical infrastructure and it must also reshape public attitudes. By designing spaces that invite interaction and awareness, architects can catalyze a cultural shift toward sustainability. Ultimately, such an approach is vital for fostering an environmentally harmonious society where waste management becomes a collective endeavor rather than an invisible burden.

7. FURTHER RESEARCH

This study has hypothesized a waste center that is expected to not only treat the waste that people produce but also the mindsets and perception of waste in peoples' mind. The main focus of this study has been on the architectural and spatial aspect of the waste management system. Further studies can be carried out to explore on the technical and financial aspects of the waste center. Aside from that it is recommended that the following areas be looked upon in any future study:

- Feasibility studies of a WTE plant
- Further studies on technical and financial

aspects of a waste to energy plant
- Investigation into the use of public spaces to retrofit already existing industrial architecture
- Public space design standards for industrial buildings
- A Bhutanese industrial architectural guideline

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