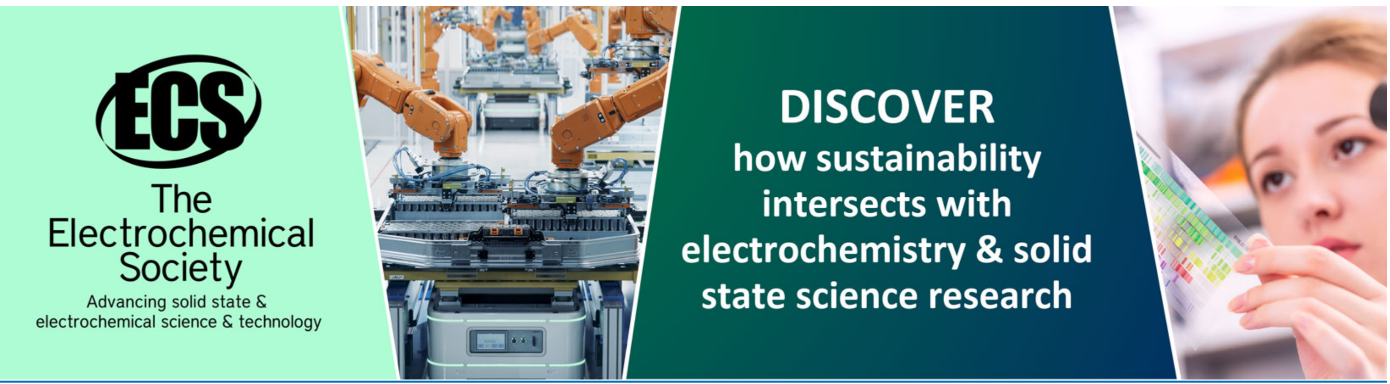
IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

A Sustainable Approach to the Prevalent Problems in Tactical Urban Construction of Temporary Structures



A Sustainable Approach to the Prevalent Problems in Tactical Urban Construction of Temporary Structures

Shiva Nandhini Sivakkumar[1*], Durga Shree Shankar[1], Jabirkhan Yahiyakhan[1], Manjunath Nochikuttai Venkatachalam[2], Dhivyabharathi Shanmugam[2], Vasudevan Mangottiri[2]

[1]Undergraduate Student, Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamil Nadu – 638401, India

[2]Assistant Professor, Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamil Nadu – 638401, India

*Corresponding author Email ID: shivanandhini.ce17@bitsathy.ac.in

Abstract

It is essential to make a check on extraneous usage of concrete in construction to reduce the urban heat island effects. As a step towards sustainability, small or temporary structures can be constructed by reusing a variety of rigid materials that are found in abundance in scrapyards. This paper emphasizes the sustainability aspects of reusing scrap materials for constructing a bus shelter using the principles of tactical urbanism. The selected materials include scrap steel pipes, wasted foam sheets, gypsum board, plastic cans and bottle caps. After minimal modifications (cleaning, sizing and shaping), they were converted to suitable panels and members of designed dimensions. The embodied carbon analysis showed that 130.23 kg equivalent of carbon dioxide is saved by not using new materials in construction. By this approach, the net embodied carbon for the entire structure is turned to be negative (-85.23 kg equivalent of carbon dioxide). On another aspect of tactical urbanism, a suitable construction methodology is designed to utilize minimal time and manpower for construction which also could reduce the carbon and energy footprints substantially. The innovative provision for using clamps on the skeleton frame enabled direct insertion of panels, thus minimizing the requirements for fasteners or adhesives. The entire structure is found to be light in weight and portable but strong against pulling loads. The social and environmental aspects of sustainability were evaluated using checklist, sectoral matrix and checklist methods. We envisage this approach in making security homes, isolation wards at times of contagious outspread, locomotive stalls etc.

Keywords: *Sustainability, Carbon footprint, Reuse of crap materials, Light-weight structure, Tactical urbanism, EIA*

1. Introduction

Thiruvalluvar, a celebrated Tamil poet and philosopher in India, remarkably noted about the intention of human interventions in a beautiful way as “A timely help is bigger than the universe” [1]. This is particularly applicable to the civil engineers who are primarily involved in creating technologically sound concrete structures, which are, however, noted as the third cause of universal deterioration by global warming and degradation. There is always a growing concern to invent suitable alternatives which can provide technologically smarter avenues that pave to the design of sustainable infrastructure, even if it would be adept and prudent to enhance the present technology [2,3]. The rapid urbanization and man's thirst to lead a sophisticated life have not only abated the available resources, but also have generated abundant wastes and scraps though many such remnants have high reuse values and capabilities [4].

Due to increased population and unsatiating demands of the urbanizing world, the number of construction projects for various utilities have increased greatly. Apart from high utility concrete buildings, the need for some minor structures like bus shelters, security homes and temporary structures like material sheds at construction sites etc., have also increased considerably. Usage of conventional construction methods may be uneconomical and also contribute to global warming [3]. Since it is inevitable to use conventional methods in construction of large structures, the deployment of smart and sustainable construction methods can be effectively applied in the design and construction of small-scale structures. The much-hyped '4R' principle- Reduce, Reuse, Recover and Recycle- however, is proven to be highly inelastic while considering the socio-economic acceptance and extension. Recycling of materials, though beneficial, is time and energy consuming. To overcome this, reusing the materials becomes essential where some minor preliminary treatments may make the material suit a better purpose and making the product economical and useful.

It is not uncommon to see that using the remnants in construction would help in regaining much wanted resources, and also in abandoning them unnecessarily in landfills and scrapyards. From the energy point of view, construction industry as such is highly energy-intensive, mostly due to the embodied energy while preparing and procuring the raw materials. In terms of the expected greenhouse gas (GHG) emissions, the construction industry has an enormous impact on the environment. In fact, this whole sector accounts for 36% of worldwide energy usage and 40% of carbon dioxide (CO_2) emissions. The reinless carbon footprint increase by the usage of fresh industrial products can be controlled by reusing the materials. According to Steel Scrap Recycling Policy, the use of every ton of scrap shall save 1.1 ton of iron ore, 630 kg of coking coal and 55 kg of limestone [5]. There shall be considerable saving in specific energy consumption as the same will reduce from 14 MJ/Kg in blast furnace (BF)/basic oxygen furnace (BOF) route to less than 11 MJ/ Kg in electric arc furnace (EAF)/inductive furnace (IF) route, thereby saving the energy by 16-17%[6]. It also reduces the water consumption and GHG emission by 40% and 58% respectively.

The popular methods of addressing the sustainability in civil engineering include making of green concrete and recycling of reinforcements which have proved least environmental impacts and high life cycle sustainability. While such innovations keep evolving for high utility structures, some small ideas for small-scale construction can combine to create a truly sustainable construction industry. Such approaches are to be multi-directional in addressing the existing environmental problems caused by construction materials as well as practices and also to bring down the cost of construction [7-9]. Ideas with tactical urbanism methods of construction come into play where construction is done in a simpler manner without creating disturbance to the adjacent neighborhood [10,11]. Tactical urbanism is a 'short term action for long term' approach to community revitalization using low-cost, accessible place making interventions that inform long-term investment. It was initially explored in early 2000s, but evolved as a common term in the previous decade [12]. As it combines an open development process with the creativity unleashed by social interaction, this is highly appreciated by the citizen groups, business groups and non-profit and government organizations. It has recently gained momentum and is being highly anticipated for its wider application scenario [13-15].

Following the idea of Heineken (used glass block as a housing solution in 1960), Illac Diaz and My Shelter foundation constructed the 'Bottle school' with a combination of glass bottle panel and 2-liter plastic bottles [15,16]. Recently, people have created small scale structures using the waste plastic bottles, thereby, adding another utility to the bottles as well reducing their presence in the landfills. These methods substantiate the tremendous possibility to use the available scrap materials to construct similar small-scale structures. This paper deals with an approach to rehash the scrap materials into an easily-constructed public utility structure. The objectives of the present study are (i) to construct a bus shelter by enhancing the reuse of rigid materials that are abundantly available in the scrap in place of new materials, (ii) to help in reducing embodied energy as well as to have tangible economic benefits, and (iii) and to emphasize the social significance of using renewable and reusable resources that ultimately leads to reduction in energy consumption and waste by means of social consultation methods.

2. Materials and methods

2.1. Design Approach

The skeleton of the bus shelter structure is modeled in STAAD Pro® software and analyzed for its structural integrity and stability (Figure 1). A basic framework is prepared by keeping three sides closed, and permitting easy access through one side. Specific conditions of loading and ground support are implemented in the design to optimize the dimensions and joints for the structural components.

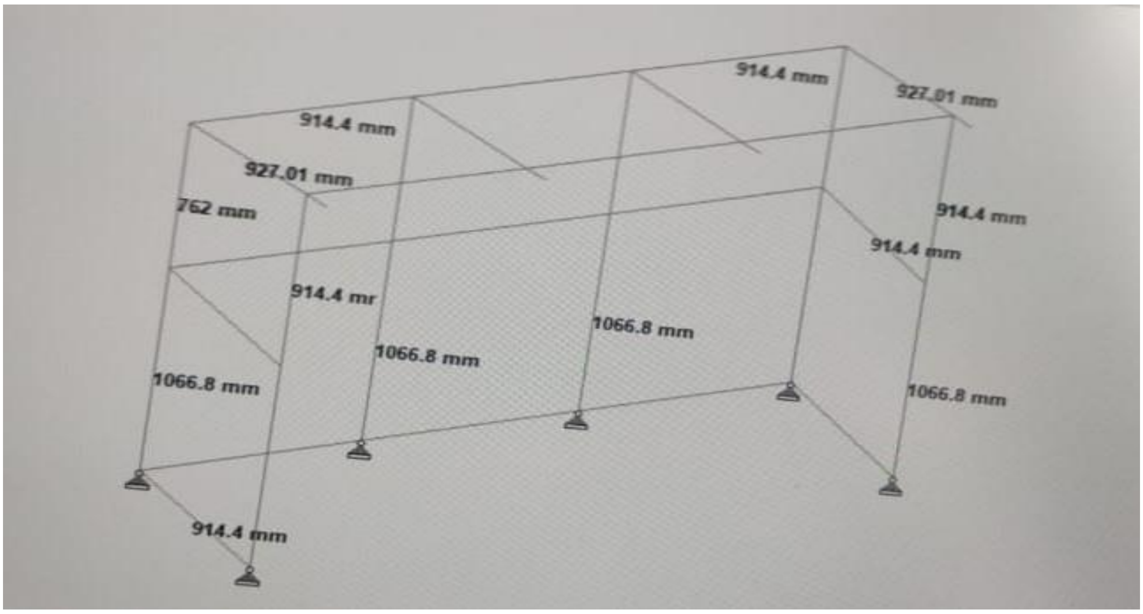


Figure 1: Line Diagram of the Structure in STAAD Pro®

2.2. Materials Selection

Sustainable materials are highly durable and can be incorporated in different technologies, such as minimizing energy footprint, capturing CO_2 while reducing pollution. The local scrapyard was explored and the availability of various such materials were noted. Then the availability of the same globally, was checked. The materials were studied for their suitability in the construction of bus shelter and were chosen. Scrap steel members were selected to prepare the main framework, and the abandoned Styrofoam sheets (thermal insulating material discarded from the air-conditioning pipelines), plastic barrels and ultralite bits (previously used as roof sheets) were chosen. Chicken mesh was purchased commercially to make the proper binding of these materials while preparing the wall and roof panels.

2.3. Prefabrication and Treatment

IOP Conf. Series: Materials Science and Engineering **955** (2020) 012013 doi:10.1088/1757-899X/955/1/012013

1. The steel members were cleaned to make them free from rust and resized to get the planned dimensions.
2. The Styrofoam were pressed to make flat surfaces and cut to dimensions.
3. The plastic barrels were beaten into flat sheets of designed dimensions.

2.4. Fabrication

2.4.1. Fabrication of Structural Members

The treated steel members are cut into suitable sizes according to the design. The joints for the lap metal plates are pre-welded into each member so that welding does not need to be done at the time of erection of the entire structure. The holes for bolt connections are located and drilled accordingly. Channel shaped grooves were provided on the inner edge to enable the panels slide in and get fixed at the joints easily without any hassle. This method, later helped in reducing the time of erection and also conserve man power and energy.

2.4.2. Fabrication of Panels

The pressed Styrofoam and plastic barrels were sandwiched, each between the chicken mesh on either of the sides. Simple fasteners were used for sandwiching. Then, they were bordered using ultra lite to enhance their rigidity.

2.4.3. Fabrication of the Structure (Bus Shelter)

The fabricated structural members were finally arranged as per the design. Rapid construction is rendered by the clamping method used in our project and thereby accounting for tactical urbanism. The members were connected by bolting with ease since all the essential steps were completed in the pre-fabrication stage. The panels were inserted into the channel shaped grooves and it did not take much time since no adhesives or fasteners were used. By the implementation of this method, the erection of the entire structure was done in less than 25 minutes. The completely finished structure was tested against pulling.

2.5. Checks on Sustainability

2.5.1 Embodied Carbon Analysis

Since the carbon dioxide equivalent is a representative of the expected greenhouse gas emission and global warming, all the materials were evaluated for their requirement in terms of the quantity per item and embodied carbon in each of them. It is obvious that by reusing the materials from scrap, we not only reduce the need for new materials, but also extend the life period of those materials. It is substantial to analyze the Life Cycle Impact (LCI) to check the adherence of the structure to sustainability. LCI is mainly concerned with energy and carbon emissions. Study on embodied carbon values can serve the needed purpose.

2.5.2 Environmental Impact Assessment

The environmental impact of the present approach of construction can be evaluated using the conventional environmental impact assessment (EIA) tools. By considering the advantages and disadvantages of various methods for EIA, sectoral matrix and checklist methods were chosen. Every action done is linked to its impact in the sectoral matrix method and the EIA results are reliable. The checklist method helps us to inspect the positive as well as negative impacts of the structure against

IOP Conf. Series: Materials Science and Engineering **955** (2020) 012013 doi:10.1088/1757-899X/955/1/012013

various parameters. The impacts of the constructed structure in all possible ways were analyzed through those methods.

2.6. Public Perception on Reuse of Wastes

An online survey was conducted by sharing google forms on social media. It was a questionnaire for collecting data regarding the change in perception of reuse of materials at individual level. The questions were directed towards identifying the possibility of collecting the materials required for this project from the household wastes, understanding the common practices in disposing the non-degradable wastes and also in gathering the public acceptance regarding construction using those materials.

3. Results and Discussions

The sustainability characteristics of the structure are evaluated using embodied carbon analysis and the social predicament of this approach is analyzed using the tools recommended for EIA such as sectoral matrix and checklist method. In order to validate the social acceptance of the proposed solution, the results of the online survey were analyzed. The salient results from the study are described in this section.

3.1. Embodied Carbon Analysis

Since most of the reused materials are directly utilized for the construction without any treatment, it is pretty promising to evaluate the reduction in carbon footprint of this exercise in comparison to the construction using a set of fresh materials of same quality. The net embodied carbon value for each individual item were calculated by referring to the phenomenal carbon content (based on standard references) and by taking into account of the total quantity of the materials being used. The details of the calculations are provided in Table 1.

Table 1: Analyzing the embodied carbon value of various materials used

	Material	Weight per piece (in kg)	No. of pieces	Total weight (in kg)	CO2e of material (kg of CO2 per kg)	Total CO2e saved	Recovered from landfill (%)	Recovery for recycling (%)
	Members							
1	Steel*	1.6	32	57.6	2.05	-115.2	100	35
	Panels							
2	Chicken mesh**			5	1.6	8	-	5
3	Ultralite**			0.75	2	-1.5	20	-
4	Styrofoam**			1.5	6.735	-10.10	95	90

5	Plastic**	1.5	6	-9	100	20

*Considering the recycling rate of 35% for steel in India, the unit embodied carbon is 2.05.
**the materials are weighed totally upon their usage. (-ve sign indicates that they are reused and embodied carbon is negative since no new product is used)

Considering steel as the primary material in the construction based on its reuse potential, the net embodied carbon was found to be significantly depending on the proportion of steel utilization in construction. Apart from the panel members, steel occupies a lion share of the weight (88.8%), thus contributing towards making the net carbon value to be negative. Though not carbon-friendly, the utilization of ultralite and Styrofoam as panel members has tremendous reuse potential and can accommodate variations in the architectural design. The total embodied carbon value is -127.8 kg equivalent of CO_2. The total value obtained is negative indicating the non-usage of new materials. Since embodied carbon value is the indicative measure of the LCI of any structure, the above analysis stands as a proof that our structure does not cause any degradation to the environment.

The tactical urbanism technique of providing grooves on the inner surface of the steel members to insert the panels avoids the CO_2 emission during welding and man power during bolting. The method conserves energy to a greater extent and prevents release of pollutants into the atmosphere. Based on the trial experiments conducted, it is found that with the help of four persons, the entire construction could be completed in mere 20 minutes for the above-mentioned dimension, thus greatly reducing the manpower and time requirement.

3.2. Comparison of Tactical Urbanism with Conventional Techniques

Many ideas for sustainable construction keep budding and some efforts have been successful. The successful works are studied and our work is compared with them to show the beneficial outcome of our proposal.

Table 2: Comparison with previous works

Dimensions	Materials used	Advantages	Disadvantages	Reference
Space sufficient to accommodate 5 people	Bamboo	Reduces CO_2 in air, cheap, strong	Joining of members is difficult	7
Mentioned that dimensions vary according to the locality	Herculite® glass panels, steel	Strong, abrasion resistant	Relatively costly	8
1.2 to 1.5 m (width) and 2 to 5 m (length)	Bricks, concrete, glass, metal and composites	Requires less maintenance	Relatively very costly	13
1.5 m (width) and 5 m(length)	Wood, concrete base, glass, steel	Strong, durable	Deforestation, costly	14
1.2 m (width) and 3 m (length)	Scrap steel, expelled Styrofoam,	Very cheap, strong, doesn't	The steel members need to be maintained	Present study

	plastics, chicken mesh, ultra lite	use new materials	free from corrosion

Many other similar works have been done using used glass bottles, PET bottles and most of the works have involved the usage of glass [15]. It is true that glasses don't affect the environment. However, reuse of materials has to be promoted. The usage of bottles in construction is appreciable, but it has to be noted that glass breaks easily. Non-problematic and easy handling materials should be used in the public access structures and hence our work qualifies the necessary criteria [17,18].

A preliminary structural safety analysis using STAAD Pro® have proven that our structure would stand safe against the loads. However, the light weight of the panels used would save people from getting injured even at the time of collapse. Hence, the proposed structure would be safe to the environment as well as the people accessing it in all means. Providing some add-ons like trash receptacles, lighting using solar panels, route maps etc., render the structure more suitable for use.

3.3. Environmental Impact Assessment

The effect of the existence of the structure on the environment and its extent of adversity are determined by Environmental Impact Assessment methods.

3.3.1. Sectoral Matrix Method

Sectoral matrix method is used to get reliable results of EIA and the various stages in our project starting from material procurement to the final erection of the structure are assessed for their impacts on various parameters (Figure 2).

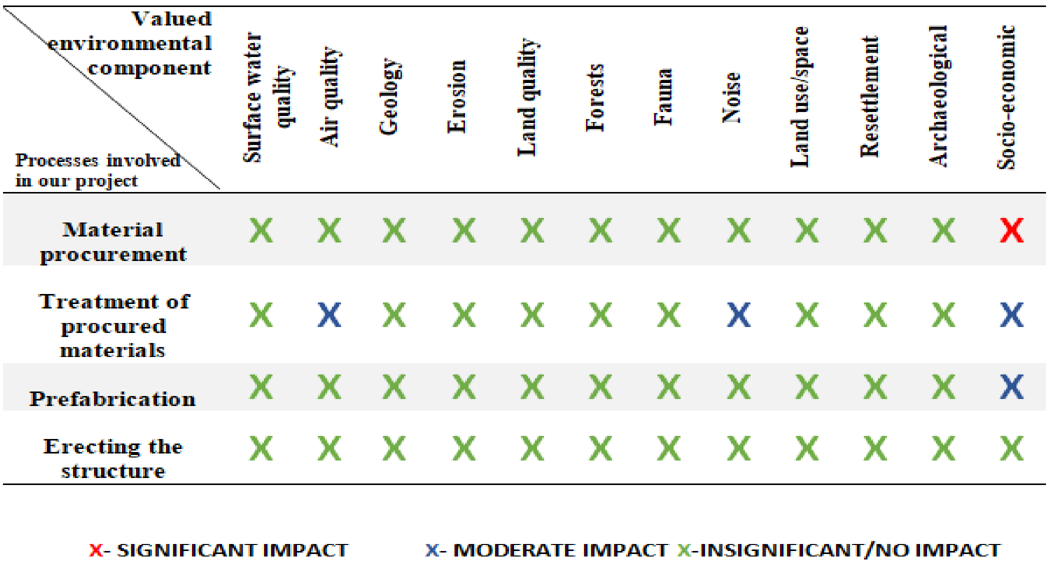


Figure 2: Environmental Impact Assessment using Sectoral Matrix method

The analysis using sectoral matrix method indicates that most of the processes involved have insignificant or no impact on the environment and hence the structure is safe in all aspects. The moderate impact can be easily made to less by some simple improvisation to the structure so that it can free from creating such impacts. The significant impact of material procurement on socio-economic aspects is a positive impact. It is because, the material costs are very much reduced and thereby making the structure economical.

3.3.2. Checklist Method

Various criteria under quality of life, leadership and resource allocation are listed and checked so as to find the real feasibility and worth of the idea (Table 3).

Table 3: Checklist method of EIA

	Description	Metric	Project meets criteria
Quality of Life	Enhance public health and safety	Efforts to exceed normal health and safety requirements, taking into account additional risks in the application of new technologies, materials and methodologies.	✔
	Enhance public space	Plans and commitments to preserve, conserve, enhance and/or restore the defining elements of the public space.	✔
Leadership	Foster collaboration and teamwork	The extent of collaboration within the project team and the degree to which project deliver processes incorporate whole systems design and delivery approaches.	✔
	Provide-e for stakeholder involvement	The extent to which project stakeholders are identified and engaged in project decision making. Satisfaction of stakeholders and decision makers in the involvement process.	✔
	Pursue by-product synergy opportunities	The extent to which the project team identified project materials needs, sought out nearby facilities with by- product resources that could meet those needs and capture synergy opportunities.	✔

	Improve infrastructure	The extent to which the design of the delivered works integrates with existing and planned community infrastructure, and results in a net improvement in efficiency and effectiveness.	✔
Resource Allocation	Extend useful life	Extent to which renewable energy resources are incorporated into the design, construction and operation.	✔
	Reduce Net Embodied Energy	Percentage reduction in net embodied energy from a life cycle energy assessment.	✔
	Use Recycled Materials	Percentage of project materials that are reused or recycled.	✔
	Divert Waste from Landfills	Percentage of total waste diverted from disposal.	✔
	Provide for deconstruction and recycling	Percentage of components that can be easily separated for disassembly or deconstruction.	✔
	Use renewable energy	**Extent to which renewable energy resources are incorporated into the design, construction and operation.**	✔

3.4. Change in Public Perception on Waste Reuse Culture

It is important to know the public opinion and work accordingly for the success of any developmental project. Online survey has been made and the observations are listed below (Table 4).

Table 4: Survey results

Description	**Positive response (%)**
Presence of high dense plastics in household wastes	54.9

Presence of unused GI/Steel angles, pipes, bars etc.,	61.4
Presence of expelled Styrofoam and insulators from A/C units	63.2
Improper handling of the above stated wastes such as throwing directly in garbage	64.9
The wastes being delivered to the scrapyards	26.3
Reuse of wastes for DIY and valuable purposes	8.8

From the above survey results, it is evident that most of scraps are mishandled. Also, when appreciable quantity of the materials for the project can be collected from households alone, the industrial and commercial wastes can account for greater development projects if procured and handled in an appropriate manner. 29.8% of people from rural areas have answered similar to that of people in urban areas indicating no much difference in handling of wastes. Proper handling of the scraps is done only by nearly 35% of the community. Hence it is essential to educate the community regarding the same.

When the idea of constructing structures using the available scraps was proposed to the public, 50.9% of the people questioned answered that it is a highly beneficial idea and 49.1% of the people answered it is a good proposal. However, when the idea is actually executed, the expectations on the favorable results are likely to be changing. A relative grading method is evolved to explain the variability in the expected outcome as follows (Table 5). The grades are based on the survey and EIA results and are marked out of 5. It is inferred that majority of the concern were about better environmental sustainability irrespective of the size and scale of the project activity. People also shared their thoughts about expanding these projects laterally over the community, if not vertically by up-scaling the features. There is also a growing concern about incorporation of smart tools for information dissemination and communication in such sustainable structure, which can add-up their social acceptance value considerably.

Table 5: Evaluation of change in perception about waste reuse

Criteria	**Relative grade for expectation of change in response (out of 5)**
Change in public attitude towards handling wastes	4

IOP Conf. Series: Materials Science and Engineering **955** (2020) 012013 doi:10.1088/1757-899X/955/1/012013

Diverting waste from landfills	4.5
Controlled Pollution	4.8
Feasibility of providing such structures in large numbers to the community	4

4. Conclusion

Present study proposes an innovative solution for reusing rigid, non-degradable scrap materials in the construction of sustainable building, specifically about the construction of a bus shelter. By incorporating the waste materials and by following the principles of tactical urbanism, the entire construction is found to be promising in terms of the net embodied carbon content as well as reduced environmental impacts. The outcomes of the study revealed the major advantageous outcomes of the structure as high reuse value, non-destructive dismantling after use, cost-efficient, non-polluting, less diversion of wastes to scrapyards, rapid construction and reduced embodied carbon content. Using this approach, it is possible to develop many other small-scale structures similar to bus shelters along with movable ones to extend the utility of the proposed idea.

"Little drops of water make the mighty ocean"- Small steps towards sustainability to create a better environment for the future generations.

References

[1] Sastry, Kadayam Ramachandra Ramabhadra 1973. *Sangam Publishers*.
[2] Cole, R.J., 1999. *Building Research and Information*
[3] Forsberg A. & von Malmborg F., 2004. Tools for environmental assessment of the built environment. Building and Environment
[4] Madurwar MV, Ralegaonkar RV and Mandavgane SA., 2013. *construction and Building materials*
[5] https://steel.gov.in/sites/default/files/Steel%20Scrap%20Recycling%20Policy%2006.11.2019.pdf
[6] Harvey LDD, J. Sustain. Metall https://doi.org/10.1007/s40831-020-00276-5
[7] Wood, Christopher, and Mohammed Dejeddour, 1992
Impact Assessment **10.1**
[8] Gilpin, Alan, and Alan West, 1995 *Environmental impact assessment: cutting edge for the 21st century*. Cambridge University Press
[9] Amores, Marianne Therese, and Nirmal Krishnani 2014 *"Towards a Better Alignment of Green Building Rating Tools with Environmental Sustainability."*
[10] Silva, Paulo. *Environment and Planning B: Planning and design* .
[11] Hinthel SK, Sh H. Hussein, and Aldabbagh JA 2020 *Conference Series: Materials Science and Engineering*
[12] Pfeifer, Laura 2013 *Montereal*, *Canada Page*
[13] Lupíšek, Antonín, et al. 2015 *Energy Procedia*
[14] Farzad Hatami, Mahjoobin, and Hatami 2016 *TODJAC*

IOP Conf. Series: Materials Science and Engineering **955** (2020) 012013 doi:10.1088/1757-899X/955/1/012013

[15] https://www.thebetterindia.com/104109/pet-bottles-construct-homes-bus-shelter-hyderabad-bamboo-house-india/
[16] http://www.naturalshelter.com/overview
[17] Van Hinte, Ed, Césare Peeren, and Jan Jongert. 2007.*Superuse: constructing new architecture by shortcutting material flows*. 010 Publishers
[18] Cousins, Keith. 2002.*Polymers in building and construction*. iSmithers Rapra Publishing