# Investigating the Potential for Standardization of Glass Reinforced Polymer (GRP) Shutter Molds Designs in Bridge Projects in the UAE

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## Abstract

This paper addresses the potential for design standardization of bridge construction moulds as a means to minimize waste and cost. Specifically, the paper looks at the potential for standardizing the design of bridge Glass Reinforced Polymer (GRP) shutter moulds that typically vary in size and design based on project-specific requirements. Environmental and economic sustainability aspects are addressed using a two-tiered approach views of construction experts were solicited, and production-to-demolition and disposing costs of a sample of completed projects estimated. There appears to be a consensus that there are significant benefits from standardizing the design of the modes including material waste reduction, cost savings, shorter procurement processes and possibly the reuse of shutter moulds. Given the size of the construction sector and its contribution to material and energy consumption and harmful emissions, and non-hazardous waste, the potential savings are significant.

**Keywords:** GRP; Shutter moulds; Bridge construction; Sustainability; Pier

## 1 Introduction

Globally, the construction industry is a major contributor to improving the quality of life in society, however, it still produces 45% to 65% of waste that is disposed in landfills, 35% of global $CO_2$ emissions, and nearly 30% of all greenhouse gas emissions, which further confirms the need for construction companies and government entities to focus on the implementation of effective strategies and policies to reduce the environmental impacts, as per (Li. *et al*., 2002). It is evident that the construction industry is experiencing challenges such as low level of automation in design and construction, and the scarcity of natural resources as well as the constant need for new “sustainable” construction methods. Accordingly, there is a need to address such challenges by looking at current practices and exploring the possibilities of enhancing performance in the industry, particularly for bridge projects where the reduction of costs and $CO_2$ emission, and energy savings would contribute immensely to improving the sustainability aspects. Therefore, according to (Qu *et al*., 2020) the future is seen to be moving in the direction of standardization of component production and manufacturing, equipment mechanization and automation and reducing complexity of structural elements assembly.

When looking at the design of bridges, specifically piers, they are designed primarily as a strong support system for the bridge superstructure, but they can also be aesthetically pleasing to the eye of the viewer. Therefore, sizes and shapes can vary in order to meet the demands of clients, which poses a challenge to designers where they have to be innovative and always come up with new designs thus increasing the potential for environmental impacts due to the increased number of bridge pier moulds used in every new project. To build a bridge, there are several types of moulds that can be used, such as column, beam moulds, wall, slab, staircase and customised moulds. Bridge piers are usually comprised of columns and heads, or a pier cap, which are customized in dimensions and shape based on the design requirements.

Qu *et al*. (2018) stated that in recent years, the design and construction of bridges have experienced advancements and innovations, which contributed time and cost savings, as well as simplifying the construction process e.g., Tandon (2019) mentioned that the use of pre-casting has accelerated the delivery of bridge projects by achieving several milestones, including reduction of environmental pollution to enhance the sustainability of a project, minimizing disturbance to traffic during construction with aesthetic quality of construction to support the social pillar of sustainability, in addition to accelerating construction and choice of durable structural components that boost the economic benefits through cost-reduction. As a result, the standardization of pre-casting moulds inside the casting facility is a major factor which determines the cost and speed of bridge construction projects.

As mentioned by Fitzgerald *et al*. (2021), Fibber reinforced plastics or polymers (FRP) are commonly used in the construction industry. They are made of composites that include either carbon, glass or aramid as the major fibre, and mixed with other elements like silica sand or limestone at a specific temperature. Usually, the glass fibre is named after the main element that is added. Accordingly, there is Carbon Fibre Reinforced Polymer (CFRP), Glass Fibre Reinforced Polymer (GFRP or GRP) and Aramid Fibre Reinforced Polymer (AFRP). Sundaram (2009) mentioned that the use of GRP material in bridge piers has been dominant over the traditional material like steel, aluminium and concrete, mainly due to its favourable traits like its ability to be designed in various shapes, as well as its long-life expectancy, corrosion resistance and uniform appearance. However, there are associated impacts of using GRP, such as the high emissions due to the complex production stages. However, according to Li *et al*., (2022) it still has lower $CO_2$ emissions compared to steel.

Although an experimental study of recycling GRP into concrete composite has shown that GRP waste can be used as a partial replacement for fine aggregate and an admixture in cement concrete, it still requires further investigation to evaluate durability and other compliance tests, which does not provide a feasible solution for the effective management of GRP waste, according to (Osmani & Pappu, 2010).Therefore, the reduction of construction waste should be considered, as it will be a more efficient approach compared to using treatment options that are costly and energy-demanding. A study in Wuhan, China conducted by Li. *et al*. (2022) revealed that construction managers with higher levels of education are willing to reduce construction waste as they understand the associated benefits, but fail to do so due to the tight project schedules, insufficient budgets, and the design changes factor which affects the waste reduction process, thus confirming the need for policies and regulations to regulate the use of GRP material and manage the associated waste.

The literature shows lack of studies in the UAE about the generation of waste and potential environmental and economic costs associated with bridge projects. Also, there is absence of information from the bridge construction industry about the effects of using different designs for bridge pier moulds and the willingness to consider standardization of designs to minimize waste generation. Given the importance of addressing waste associated with the construction industry, and given the fact that bridges are a main structural element of the infrastructure in any country, the aim of this work is to evaluate the sustainability aspects of bridge projects through the assessment of the environmental and economic impacts of construction moulds in bridge projects.This will be achieved by investigating whether there is waste associated with the GRP shutter moulds used in the construction of bridge projects, evaluating the environmental and economic impacts of the GRP materials during the manufacturing stage and exploring the perception of industry experts towards standardization of GRP shutter moulds design and the associated possible benefits.

## 2 Methodology

The research follows a pragmatic philosophy, with an abductive approach and a non-experimental strategy for exploratory purpose. Mixed-methods are used to address the qualitative and quantitative data obtained through interviews and a case study, respectively. The descriptive (qualitative) section includes literature review and interviews with subject matter experts (SMEs) in the field of bridge design and construction within the UAE, while the quantitative section is carried out by compiling a case study of different bridge projects that have been carried out within the UAE in the last 10 years. The interviews follow a non-probability snowballing sampling strategy to reach saturation, where: (i) Sampling population included: SMEs in construction projects in UAE; (ii) Study population: SMEs in bridge projects in UAE; (iii) Target: Minimum of 10 experts; and

(iv) Sampling frame: Mobile and email communication.

### 2.1 Data Collection

The case study section focused on twelve (12) real bridge projects constructed in 3 emirates (Dubai, Sharjah & Ajman), and consisted of data regarding quantities, sizes (dimensions), weights (in kilograms), and the cost (in Dirham) of the different shutter moulds that were used to construct the bridges (focusing on GRP moulds for heads and columns). Data was gathered to investigate the environmental effect of GRP moulds by calculating the emitted $CO_2$ gas, the Embodied Energy (EE) needed to produce the GRP moulds, the economic cost of the moulds manufacturing according to the costs obtained from the vendors that carried out the bridge projects, and the demolition cost (including loading, transport, and municipality waste management fees).The duration was specified to target the last 10 years, due to the ease of obtaining relevant documents, and the increased supply of bridge projects in recent years to ease the traffic jam issues resulting from the increased vehicle movements.

Subject Matter Experts (SMEs) were also approached for the participation in interviews. The sample collection followed non-probability convenient sampling approach to reach saturation by targeting project, technical and construction managers, in addition to project or structural engineers and technical consultants, with a specific criterion of having previous experience bridge construction projects and having technical experience of no less than five (5) years. Sampling limitations included time constraints and the specificity of the topic of interest being design and construction of bridge projects. This resulted in obtaining ten (10) SME participants, which satisfied the saturation limit for qualitative non-probability sampling.

The components of the interview were divided into two sections. The first, section included a declaration of consent to participate in the questionnaire, while the second part consisted of sixteen (16) questions related to different aspects of bridge design and construction, including Yes/No questions and descriptive aspect like reasons, factors or possible benefits. Due to difficulty in reaching the participants on site and given their commitments, they agreed to participate in a written format by answering the questions via email correspondence, while providing their personal contact information for further correspondence, if needed.

### 2.2 Data Analysis

When a product is produced, it requires a certain amount of energy during the manufacturing process, and that energy demand is a necessity throughout all the stages of production. According to Hanania *et al.* (n. d.), this includes raw material extraction, transportation, manufacture, assembly, installation, disassembly, and demolition of that product, which provides an idea of how sustainable this product is by showing how much energy is consumed through the entire life-cycle, which allows for lowering the impact on the environment by choosing products that have lower embodied energy. Simply said, simple materials like wood have lower embodied energy compared to highly processed material or complicated manufacturing processes, and the same applies for materials sourced closer to the homeland compared to those imported and transported from thousands of miles away. Moreover, the embodied energy of any object can be calculated by knowing what type of material is present within the object, the quantity (weight) of that material. Embodied Energy is then measured using "energy per unit mass" scale, such as mega joules per kilogram, according to Hendricks (2014). When it comes to GRP material, it is estimated to have an embodied energy rate of 100 Mega Joule (MJ) per kg of GRP and releases about 8.1 kg of $CO_2$ per kg of GRP, as stated by (Hammond *et al.*, 2011).

The quantitative portion (case study) had undergone statistical analysis to calculate the parameters indicated in Table 1, including total weight of all GRP moulds used in the bridge projects, the Embedded Energy (EE) consumed during mould manufacturing, Total Emitted $CO_2$ during manufacturing, and the total cost of manufacturing in AED (as shown in Table 3).Calculations were performed as follows:

$$Weight\ of\ GRP\ Mould\ (kg) \times factor\ (8.10) = X\ kg.\frac{CO2}{kg}\ of\ GRP\ (CO2\ Emissions) \tag{1}$$

$$Weight\ of\ GRP\ Mould\ (kg) \times factor\ (100) = X\ \frac{MJ}{kg}\ of\ GRP\ (Embodied\ Energy\ of\ EE) \tag{2}$$

$$Weight\ of\ GRP\ Mould\ (kg) \times factor\ (0.4) = X\ Dirhams\ \ (Cost\ of\ Demlition) \tag{3}$$

The data from the qualitative portion of the research (interviews) was analysed using Microsoft Excel to extract the answers of the participants and perform descriptive analysis using graphical representation and calculation of frequencies and percentages of the answers.

## 3 Results and Discussion

### 3.1 Bridge Projects Case Study

Based on the data collected (Table 1) the average number of mould designs per bridge project was found to be two (2) with some of the projects using up to three (3) different designs of moulds per bridge, and a quantity of seven (7) moulds (including replicates of the same design to facilitate project delivery). Data also suggested that none of the projects shared the same pier designs, evident by the different dimensions and shapes provided in the project sketches, thus moulds from one project could not be reused in another project. In addition, the collected data (Table 1) showed that the combined weight of pier shutter moulds from the 12 projects was around 121 tons of GRP (assuming an average of 2 moulds per project multiplied by the average cost of a single mould), with an average of 4.8 tons for a single GRP Pier Shutter Mould and an average of 9.9 tons per project. Moreover, based on the current market, the average cost of a single pier shutter mould was found to be around AED 96,707 and about AED 193,413 for two mould per project, all of which had an average of 39,228 kg of $CO_2$ during manufacturing of a single GRP mould, and an average of 96,707 Mega joule (MJ) of energy consumed per kg of GRP produced for a single GRP mould.

**Table 1:** Sum and Average Statistics of 12 Bridge Projects Executed Between the Years 2014-2020 across Different Emirates in the UAE

| GRP Shutter Mould Aspect | Weight (kg) | Embodied Energy (MJ per kg of GRP) | $CO_2$ Emissions (kg of $CO_2$ per kg of GRP) | Manufacturing Cost (AED) | Demolition Cost (AED) * |
|---|---|---|---|---|---|
| Sum | 121,075 | 12,107,500 | 980,708 | 2,417,665 | 48,430 |
| Average per mould | 4,843 | 484,300 | 39,228 | 96,707 | 1,937 |
| Average per project (2 moulds) | 9,868 | 968,600 | 78,457 | 193,413 | 3,874 |
| Note: Values calculated based on 25 GRP moulds used in 12 projects.<br>*: Cost of demolition includes loading, transport, and municipality waste management fees. | | | | | |

Through examining the case study of the bridge projects, the following points were noticed: (i) there was no standardization of design amongst the dimensions of the piers heads and pier columns shutter moulds, owing to the fact that the dimensions were not uniform (each project had a different design, resulting in new shutter moulds to be built); (ii) some projects required only one shutter mould for the pier head or pier column, which was reasonable, and showed that either there was uniformity in the design, which did not require having more than one type of shutter mould, or that the size of the bridge itself was not very large; and (iii) several projects required multiple types (designs) for the pier head, and also multiple quantities (units) of the same pier head, which was probably due to the size of the bridge and the different shapes incorporated into the design, therefore requiring multiple design. Table 2 below demonstrates such a case:

**Table 2:** Example of a Single Bridge Project Showing the Potential of Savings in Embodied Energy, $CO_2$emission and Economic Savings in Case of Standardization of Pier Head Design

| Description | Qty of moulds | Weight (Kg) | Embodied Energy (MJ/kg) | $CO_2$ (Kg.$CO_2$) | Manufacturing Cost (AED) | Demolition Cost (AED) |
|---|---|---|---|---|---|---|
| Current Scenario (No Standardization): | | | | | | |
| **Total:** | 7 | 24,250 | 2,425,000 | 196,425 | 477,945 | 9,700 |
| Proposed Scenario (Standardization): | | | | | | |
| **Total:** | 3 | 10,749 | 1,074,999 | 87,075 | 212,235 | 4,300 |
| **Amount of Saving:** | **4** | **13,501** | **1,350,001** | **109,350** | **265,710** | **5,400** |
| **Percentage of Savings:** | **57%** | **56%** | **56%** | **56%** | **56%** | **56%** |

The above estimates of potential savings were based on one project that had seven (7) types of moulds, which were standardized to 3. It is possible to generalize such figures on other bridge projects, however, the potential savings when applying such standardizations on a portfolio level vs.

project level is substantially increased. When the dimensions of bridge elements are standardized across the country, shutter moulds could be reused not only in a specific project, but also across different projects within the country, where mould costs will diminish and contractors would allow for only maintenance cost of those moulds, at which point the potential savings will way surpass those estimated in Table 2. The same was witnessed in precast of houses in UAE, were developers standardized design and created different prototypes to accelerate construction duration and reduce precast mould costs, were in many projects the mould cost becomes almost null when reused to build walls and slabs of hundreds of villas within individual projects.

### 3.2 Subject Matter Experts (SMEs) Interview

To determine if standardizing the designs of moulds reduces the negative effects on the environment, structured interviews were conducted with ten (10) industry subject matter experts (SMEs) from nine (9) construction companies in the UAE to explore current perspectives as engineering professionals towards designing & constructing bridge projects. Among these experts, the majority held at least 10 years of experience in the bridge construction industry, and included a variety of professionals, such as managers, engineers and a consultant, with 80% of them having previously worked on 1-10 bridge projects.

As shown in Table 3, eighty percent of participants said that typically, there were around two (2) to five (5) types/sizes of bridge piers in one project. Most respondents confirmed that the project or pier design is the main reason for using more than one type of mould in a single project, while the rest stated a variety of reasons like “site restrictions”, “project duration”, “number and size of bearing” and “carriageway width and proposed structure” just to name a few. Majority of the respondents also said that pier moulds contribute to a maximum of ten percent (10%) of project cost. There are several factors that determine the number of moulds required for a project. The respondents said that project duration, shutter mould and project cost, project construction method/work strategy plan, and number/type of piers are the main factors that determine the number of moulds required for a project.

Also, the respondents agreed that GRP is the most commonly used material in making shutters for bridge piers and when asked if they reuse the shutter materials for new projects, only thirty percent (30%) said yes while sixty percent (60%) said they don’t reuse these materials and most responded that the change in pier and architectural designs are the main reasons. Meanwhile, the majority of the respondents that did not reuse materials for new projects could not determine nor had usage for these materials, which more likely becomes waste materials, and when asked what they do with these materials after a project is completed, majority said they dispose of it at waste management point with demolition.

Additionally, experts have been asked if the design of piers can be standardized to maximize the use of shutters between various projects, and the majority of the respondents affirmed that the standardization of design in bridge piers in which they have mentioned that reuse of shutter moulds, material waste reduction, cost savings, and shorter procurement process are among the main benefits of design standardization. The respondents were also asked on their opinion on the single project use of pier shuttering moulds and its contribution to waste and pollution. Majority of the respondents agreed that using the moulds for a single project only contribute to additional waste and pollution. Majority of the respondents also stated that the decrease on project cost and duration as the main benefits of reusing the shutter moulds in future projects.

**Table 3:** Frequency and Percentage of Participants Responses to Technical Questions in the Interview

| No. | Aspect | Frequency* | Percentage | No. | Aspect | Frequency* | Percentage |
|---|---|---|---|---|---|---|---|
| 1 | **Number of piers and types *** | | | 2 | **Cost of moulds in a project** | | |
| | One type / different sizes | 3 | 30% | | 1-10% | 7 | 70% |
| | 2-5 type / size | 8 | 80% | | >10% | 1 | 10% |
| | >5 types / sizes | 1 | 10% | | >1% | 2 | 20% |
| 3 | **Reasons for having more than one mould type*** | | | 4 | **Material used in moulds*** | | |
| | Project or pier design | 3 | 30% | | GRP | 8 | 80% |
| | Pier type specifications | 1 | 10% | | Steel | 3 | 30% |
| | Number and size of bearing | 1 | 10% | | Wood | 3 | 30% |
| | Orientation of super structure | 1 | 10% | | Composite of wood & steel | 1 | 10% |
| | Carriageway width & structure | 1 | 10% | 6 | **Agreement to reuse moulds** | | |
| | Available space | 1 | 10% | | Yes | 3 | 30% |
| | Site restriction | 1 | 10% | | | | |
| | Design calculation of bearings | 1 | 10% | | No | 6 | 60% |
| | Project duration | 1 | 10% | | | | |
| | Bridge width & span length | 1 | 10% | | N/A | 1 | 10% |
| 7 | **Factors determining number of moulds per project*** | | | 8 | **Reasons for not reusing moulds** | | |
| | Project Duration | 3 | 30% | | Different sizes & changes in pier or architectural design | 6 | 76% |
| | Shutter mould / project cost | 4 | 40% | | Pier aging upon multiple usage | 1 | 13% |
| | Number of piers | 2 | 20% | | Use of standard sizes only | 1 | 10% |
| | Number of type of piers | 2 | 20% | | Need for repair / adjustments | 1 | 10% |
| | Size of piers | 1 | 10% | 9 | **Agreement on reusing moulds as shutters** | | |
| | Manpower | 1 | 10% | | Yes | 5 | 50% |
| | Project Construction Method / Work Strategy Plan | 3 | 30% | | No | 2 | 20% |
| | Storage | 1 | 10% | | N/A | 3 | 30% |
| | Probability of reusing shutter moulds | 1 | 10% | 10 | **Purpose for not reusing moulds as shutters** | | |
| | Effective use of moulds (productivity) | 1 | 10% | | Sale as second-hand material | 1 | 10% |
| | Environment | 1 | 10% | | Shutter moulds | 1 | 10% |
| | Authorities | 1 | 10% | | No Usage | 2 | 20% |
| | Material used in mould | 1 | 10% | | N/A | 5 | 50% |
| 11 | **Agreement on mould standardization in future** | | | 12 | **Benefits of moulds standardization*** | | |
| | Yes | 8 | 80% | | Reuse as shutter moulds / Material waste reduction | 7 | 70% |
| | | | | | Shorter procurement process | 1 | 10% |
| | N/A | 2 | 20% | | N/A | 2 | 20% |
| | | | | | Cost savings | 2 | 20% |

<table>
<tr><td rowspan="7">13</td><td colspan="3">Actual Material Treatment upon project completion</td><td rowspan="7">14</td><td colspan="3">Effect of one-time mould usage*</td></tr>
<tr><td>Stored with cleaning and maintenance</td><td>2</td><td>20%</td><td>Waste, pollution, harmful chemicals, environmental consequences</td><td>9</td><td>90%</td></tr>
<tr><td>Disposal at waste management point with demolition</td><td>3</td><td>30%</td><td>Longer project duration</td><td>1</td><td>10%</td></tr>
<tr><td>Sale as second-hand material</td><td>1</td><td>10%</td><td>Additional storage area</td><td>1</td><td>10%</td></tr>
<tr><td>Recycled for use</td><td>1</td><td>10%</td><td>Mobilization cost</td><td>1</td><td>10%</td></tr>
<tr><td>Re fabrication of non-reusable shutters for new projects</td><td>1</td><td>10%</td><td>Waste of resources and no effective utilization</td><td>2</td><td>20%</td></tr>
<tr><td>N/A</td><td>2</td><td>20%</td><td>No effect</td><td>1</td><td>10%</td></tr>
<tr><td rowspan="5">15</td><td colspan="7">Benefits of reusing moulds*</td></tr>
<tr><td colspan="5">Decrease project cost / shutter cost</td><td>9</td><td>90%</td></tr>
<tr><td colspan="5">Decrease project duration / shutter delivery time and fabrication / Time utilization for future projects (increase productivity)</td><td>10</td><td>100%</td></tr>
<tr><td colspan="5">Decrease waste</td><td>1</td><td>10%</td></tr>
<tr><td colspan="5">No effect</td><td>1</td><td>10%</td></tr>
<tr><td colspan="8">* Frequency is calculated as one OR more than one answer per participant per question (Some participants mentioned more than one answer in selected aspects).<br>N/A: No Answer.</td></tr>
</table>

## 4 Conclusion

Based on the bridge drawings that were used for this study, most bridge piers did not vary aesthetically across different projects, and the design of these bridges had little to no differences, which is why the standardization of design for bridge pier moulds is a possibility that can be applied in future bridge projects in the UAE. This will not only help reduce the project cost and duration, which is beneficial for the clients, but also decreases the $CO_2$ emissions and waste pollution that greatly affects our environment. The contribution of this work, the first exploratory study of such a topic performed within UAE would benefit researchers as baseline to establish further research in the area of bridge construction waste.It is worth mentioning that there are some limitations associated with this research, such as that the evaluation of sustainability islimited to bridge piers only, as bridge decks and other elements are not included in the data set and scope within this research. Also, the aassessment is limited to bridges in Dubai and Northern Emirates only, with potential of expansion and inclusion of more bridge projects in different locations in future research.

Further research could be conducted on a comparative analysis of perceptions of stakeholders (i.e., designers, contractors, engineers) towards reducing and recycling bridge construction waste, and the possibility of using Structural Equation Modelling (SEM) and employing a detailed quantitative survey based on the results of this exploratory study to further understand the current perspectives of professional. Case study analysis could be performed to compare various construction and demolition waste management methods employed for the disposal or treatment of bridge projects waste. The economic and environmental effects in terms of the emitted $CO_2$ as a result of the treatment method, the required energy to treat the waste (and possible savings if reusing was an option), and the cost savings could be further explored. Such savings can be used for new bridge projects to improve the infrastructure of the country. Also, further studies should be conducted with focus on other elements and disciplines of bridge construction, and look for areas where there could be improvement in the processes and systems, and to find more element of bridge construction that can be standardized in terms of design, all in attempt to reduce cost and duration of bridge construction, which can lead to more bridge and other infrastructure projects having positive economic and environmental impacts in a city or nation.

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**Cite as**: Alzaim M.A., Alali M. & Abu-Lebdeh G., “Investigating the Potential for Standardization of Glass Reinforced Polymer (GRP) Shutter Molds Designs in Bridge Projects in the UAE”, *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0040