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Building Information Modelling (BIM) based Framework for Construction and Demolition Waste Estimation and Management

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ABSTRACT

Modern day world gives huge importance to sustainable construction and demolition (C&D). Governments and companies all over the world, are striving to develop methods, which reduce waste. A good step is to reduce, reuse and recycle (3R principle) construction and demolition waste. Essential for these activities is to have proper estimates of waste, that would be generated on construction and demolition of structures. Current practice in construction industry compromises on accurate estimation and audit of waste produced and recycled in construction and demolition. Considering this anomaly, this research is conducted to develop a BIM based system, for better waste estimation. The system is aimed towards estimating total waste produced, along with classifying waste that could be recycled or that must be disposed after building demolition. Initially, available waste estimation systems and their limitations are analysed. Consequently, a waste estimation is performed on a residential building model designed in Revit structures software. Successively, the data from Revit is input to a software programmed in C++ language to get estimates of waste. The research results into formation of a framework that estimates waste for any building required to be demolished. The framework has capability of estimating amount of total waste generated along with the amount of recyclable and disposable waste. Along with that, the framework gives an estimate of the cost of total amount of waste produced, specifying amount saved on recycling/reusing.

Keywords: Construction industry; BIM; waste management; sustainable development; sustainable construction

INTRODUCTION

Modern day lifestyle has increased construction and demolition activities. With improvement in living conditions, focus on construction of new structures and renovation of older structures has seen unprecedented rise. The thriving industry although, is facing problem due to this culture. Such trend has caused construction and demolition activities to increase to worrying levels. Excess and uncalculated activity is rendering whole industry to be unsustainable. Where increasing C&D (Construction & Demolition) is helping economics and employment in the industry, at the same time it is causing environmental damage and depleting levels of construction material. More alerting fact is the expected trend to have more elevated C&D activities in future. The modern-day knowledge and wisdom have although increased our attention towards effects of our industries on our environment. Construction industry is no different, and it faces extreme backlash and criticism due to pollution associated with C&D activities. The awareness. that communities now have regarding climate change and effects of excess construction, has forced researchers to devise ways to reduce such effects. This is required to encourage sustainable development in the industry and keep construction industry out of radar of critics.

CONSTRUCTION WASTE

The worst environmental impact by the construction industry occurs in the form of construction waste.

Construction waste can be described as any waste or debris produced in the construction process. The larger proportion of construction waste is generated in the demolition process instead of construction (Poon et al. 2001). Concrete, steel and asphalt, most common construction materials, are the most common type of construction waste as well. In general practice these materials are just dumped or incinerated causing multiple pollutants (Behzad Hamidi et al. 2013). In the era of awareness, it has become imperative for countries and organizations to work on construction waste management. Construction waste management is effective and efficient method of dealing with construction waste, to save environment

Construction waste is generated due to several reasons. The largest source of construction waste is the demolition process. Waste from demolition if dumped into fields, would cause land pollution. It although is not an avoidable process. Demolition of buildings is important for the construction industry. Not demolishing older buildings would pose safety risks for the residents. It would eventually cause depletion of available land. Another reason for construction waste is the steel reinforcement. The process of reinforcing requires cutting of steel bars and their alignment in proper dimensions. This process propels formation of excess edges which are of no use. Those steel edges get simply wasted. The use of premixed concrete is also an issue. This process demands use of concrete that is designed before and then transported. Consequently, a lot of material gets wasted due to demand and supply differences. On a lower scale, pipes and wires also cause waste. Inaccurate sizing and unusable residual parts, common in such equipment, get wasted in the process.

Most worrying effect of construction waste is the deterioration of natural environment and air. But there are other significant impacts of construction waste. One of the most prominent ones is the land pollution due to dumping. Open areas filled with piles of waste leads to huge areas, with ill aesthetics and land waste. This problem becomes a nuisance when such dumping occurs in urban areas, due to cargo and logistics issue. This causes expensive land to be utilized in unnecessary waste causes scarcity of land and housing. The second most ill effect is the depletion of construction material. Decent quality construction material is not plenty, if not recycled. The growing construction waste means we are using construction material inefficiently and causing waste due to inappropriate methods. This causes lack of availability of common construction materials. In turn it causes inflation in material rates per year. This makes construction activities tougher each year. Third most important effect is the economic loss. Generation of waste means, massive amounts of materials are being ordered that get wasted and the money is wasted. The unhealthy practices in construction industry cause wastage of materials and cost overruns, in turn leading towards financial losses for the firms and governments.

This situation demands us to forge ways that could revolutionize our ways of conducting construction and demolition activities. We need to strive to develop ways of construction and demolition that reduce waste production and encourage recycling of used material. This may be the only viable way to avoid inflation in cost of construction materials. This also gives hope of forming certain construction and demolition habits, which reduce damage to the environment. In United Kingdom, 80% of contractors involved in the field of construction in United Kingdom have responded that sustainable waste management will become an important practice by 2014 (Mc Graw et al. 2009). With this discovery, construction, and demolition (C&D) waste problem has amassed astonishing attention from both practitioners in the field and researchers around the world (Lu et al. 2011).

BUILDING INFORMATION MODELLING

Perhaps, one of the most advanced tools adopted for the purpose is BIM. BIM, in general is not defined by one definition. It includes collaborating all construction works in one system and having virtual data for various steps of construction and demolition activity. Where previous such attempts had only resulted in introduction of new planning and designing software, concept of BIM has introduced new vistas in the field. It has encouraged addition of analysis and management of the project through models and data. BIM has various components of function, which makes it a monopolistic element of advanced technologies of construction industry. Its various functions include visualization, clash detection, quantity take offs, surveying and machine guidance, scheduling, and cost estimation. The last two features are one of the most notable features from the perspective of a construction manager. The use of BIM for sustainable construction has deeper relation than just construction management. BIM has allowed better planning and designing in earlier phases to reduce emissions and cut costs. It still is nowhere near the importance that BIM has in sphere of construction management. With overwhelming use of technology, it has become faster and more efficient to calculate and manage material used or produced in construction activities. This area is the most imperative part of solutions to waste management in construction and demolition activities.

LITERATURE REVIEW

Construction waste can be described as any material and debris that is produced in the construction process and either is unwanted or is not a part of the final finished project. Pakistan roughly produces twenty million tons of physical waste annually, with an approximate yearly growth rate of nearly 2.4%, Racheal (2019). Largest city of our country, Karachi generates more than nine thousand tons of physical waste each day, Iqbal (2019).

3R (REDUCE, REUSE & RECYCLE) POLICY

This policy is the most common solution cited in literature. It is a special set of methods that could be adopted in construction, to reduce or eliminate waste. The policy consists of three elements and the first part is called "reduce". This part of the policy states, to reduce the generation of waste. It involves use of methods that are sustainable and cause less waste generation. This step is most important due the benefit that it holds. It's all easier when waste is not generated at all. The second element is "reuse". This part states to reuse construction elements or parts completely. This method is only partially adopted in widespread use. Most common instance of its use, is the use of columns of older buildings after bringing amendments. The third element is "recycled". This part of the policy instructs to recycle the material wasted in the process. This can be done in different ways. The concrete can be crushed and used as aggregate again. Steel can be taken out and cut in smaller size to be used again in structures requiring lower length.

REVIEW OF AVAILABLE WASTE ESTIMATION SYSTEMS

A waste estimation system was developed by in Portugal by Poon (2001), that would use a particular waste index, found by field survey and calculations. The index is multiplied with the GFA (Gross Floor Area) to find exact amount of waste produced on demolition of that building. This method produces mere estimations, and the method is region oriented. Due to change in culture of the industry, this index would change with location. It needs lot of verifications and revisions according to the conditions. The method gives inaccurate results because of the change in nature of every building. Construction industry is distinct from manufacturing in its product. Where construction results in unique product each time. Hence the waste produced is different as well. Amount of waste produced is different for each type of component as well. This can be observed in the field that certain components of building produce more weight than others. This renders average calculation method as inaccurate.

Another effort in the pool was done by Jalali (2007) in Portugal. This method is similar to Poon (2001) method, but it is more precise. In this method a component index is calculated for each component like floor, column etc. Those indexes are multiplied with GFA of those components only. This provides us with more accurate result but still lacks generalizations and needs revision in index values according to locality and conditions. Issues of values being vague estimates persists in this method.

Further in 2008, a method was developed by Lau (2008) in Malaysia. This method is specific to find amount of waste (in terms of volume) at the site. This method consists of forming a pyramid of waste by humping the material into that shape. Then the amount is calculated by finding the dimensions of the pyramid like Length, Width, and height. Then using the mathematical formula for calculation of volume of a pyramid, V=1/3(L x B x H). This method has many errors due to problems in forming an exact pyramid in the field. The nature of waste cannot always be such that exact shape could be made. This leads to in accurate estimates. This method also is really generalized as the type of waste forming the pyramid is not considered. Instead, this method assumes waste to have the same effect regardless of the type. That in reality is not the case in our field. The amount of waste generated needs to be categorized into different types.

Research was conducted by Behzad Hamidi (2014) in Virginia tech university USA. The research resulted in formation of a tool for waste estimation. This method involved using BIM as a tool to find cost benefit potential of a building demolition. The waste to be produced was found and divided into categories of reuse and recycle. The amount saved by recycling and reusing is calculated and compared with cost of demolition and cargo. This method provides waste estimation and management to little extent. The framework formed has a lot of weak estimation on the part of building structure. As all small components are assumed of specific properties and added into the model. The system also consists of strong human effort. As the framework doesn't include tools that process data with automation but require manual calculation and input.

Extraordinarily strong research was done by Jack C.P Cheng (2013). This research involved a BIM based system that estimated the amount of waste to be produced on performing a building demolition. The material produced is then separated into categories and cargo amount is calculated. The categorization work and the calculations are done by a C# software. This method is highly effective and gives good result. But this method is extremely specific to Hong Kong's local industry. The reason being the type of model, the size of cargo trucks and the recyclable material selected. This restricts it to be used only for the construction industry of Hong Kong.

An excellent attempt at waste estimation was done by Beatriz C. Guerra (2019). This research solved a major problem in construction waste estimation. The estimation process always overestimated amount of material required. The reason being a decrease in amount of material whenever steel reinforcements are used. The change in amount required is not calculated correctly by BIM software by virtue of the limitation of ability of this software. This resulted in less accurate results. This research formulates such factors and forms an algorithm that corrects readings according to amount deducted due to reinforcement. This is a very big leap forward in our traditional study in such regards. The normal procedure would always add the amount of concrete at place of steel reinforcement as well without deducting that amount. Although it helps in this regard, the research done is based on forming algorithms. This research does not actually produce a framework to work on waste production. This research does provide a new field to work on to get more accurate results.

After doing this review of available literature it was observed that the research conducted by Jack C.P Cheng (2013) was an advanced step towards waste estimation and involved better tools for the purpose. It still lacked, in nature the effect that Pakistan's conditions would have on the framework. Considering this research gap, it was decided to work according to Pakistani conditions in a framework like that research in Hong Kong. To devise a framework for waste estimation. This devised method contains additional features as well.

RESEARCH METHODOLOGY

REVIEWING AVAILABLE WASTE ESTIMATION SYSTEMS IN LITERATURE

The first step of this research was to review literature and analyse various waste estimation systems developed. The waste estimation systems analysed were either in use or just proposed by researchers. Such waste estimation methods were reviewed to know current research trend in this sphere of the field. They were also investigated to find a research gap to work on further and bring forth an effective framework for waste estimation and partial management. The framework developed was planned to be specific to the conditions of Pakistan.

MAKING REVIT MODEL OF THE BUILDING

The research advanced towards making a 3d model of a residential building in Revit software. Revit software is a common BIM based software, used for quantity measurement and structural calculations. The 3d model is made of a building keeping in mind the common building culture of Pakistan. The model of the building has exact dimensions of 92 ft by 52 ft. The model has an area of 4968 square ft. This model depicts construction over an area of five hundred square yards. It represents our typical construction results. The building contains five rooms in total with two rooms designated as kitchen and drawing room. The building has two identical floors of ten feet height. The building has three levels. Initially three feet level is taken as simple level over weak ground whereas other two levels show top of the two floors. Such buildings are old and rusty in most cases if constructed by ancestors. These buildings then, naturally require demolition and re construction. In such case the waste generated, and environmental damage caused is targeted to be reduced.

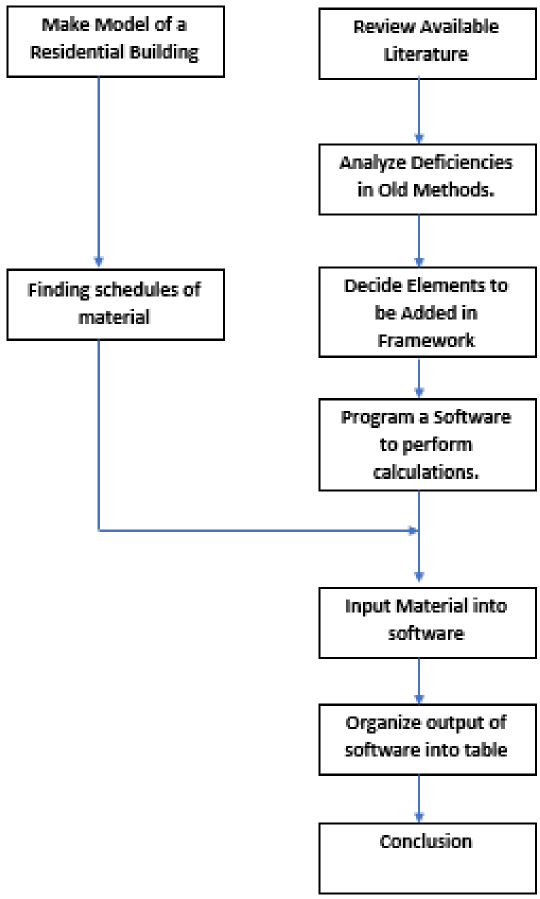

FIGURE 1. Flow chart of methodology of this research

FINDING QUANTITY OF MATERIAL FOR THE MODEL

At this stage, the model was ready. Its data automatically stored in Revit due to the software's designed procedure. Among the data stored, only some information was of our use and hence was found by certain operations. The operations of most importance for us were the material take-off, quantity take-offs and schedules. Schedule was enough to fulfil our requirements. The quantities of dissimilar materials used in the building were found by evaluating quantity take-offs of various components of the building. The software itself makes calculations for the volume of material in each component. The volumes found were later used to find mass of materials in those .components

CODING OF C++ SOFTWARE

Once the quantities of materials were found in the software, we required some way to transform that volume quantity into more usable mass terms. A C++ software was programmed in code blocks console for the purpose. The software is programmed to input volumes and calculate amount of mass of various types of materials by using densities for the calculation. The software also outputs total amount of material to be sent for reuse/recycle and the amount of material to be sent to sorting and dumping facility. In this research material containing concrete and steel is considered fit for reuse/recycle. Other materials such as plastic and wood are sent to sorting and dumping facility. The software performs such activity to estimate quantity of each type of material, which would be produced on performing the demolition process. The logic behind this step remains the fact that all material in the building should be produced in the field on performing demolition. The estimate specifies the amount of material that would be wasted and the amount that could be used for good. The software in addition output number of trucks required for transportation of this cargo. The software in its last output stated the approximate cost of the material being sent for reuse/recycle. This tells us the cost that could be saved by us on reusing or recycling that product for future construction use.

RESULTS AND DISCUSSION

THE MODEL OF THE BUILDING

A model of a residential two floor building, typical in Pakistan, was made in the process of this research. The model was made in Revit structures software due to its better features at storing and analysing data

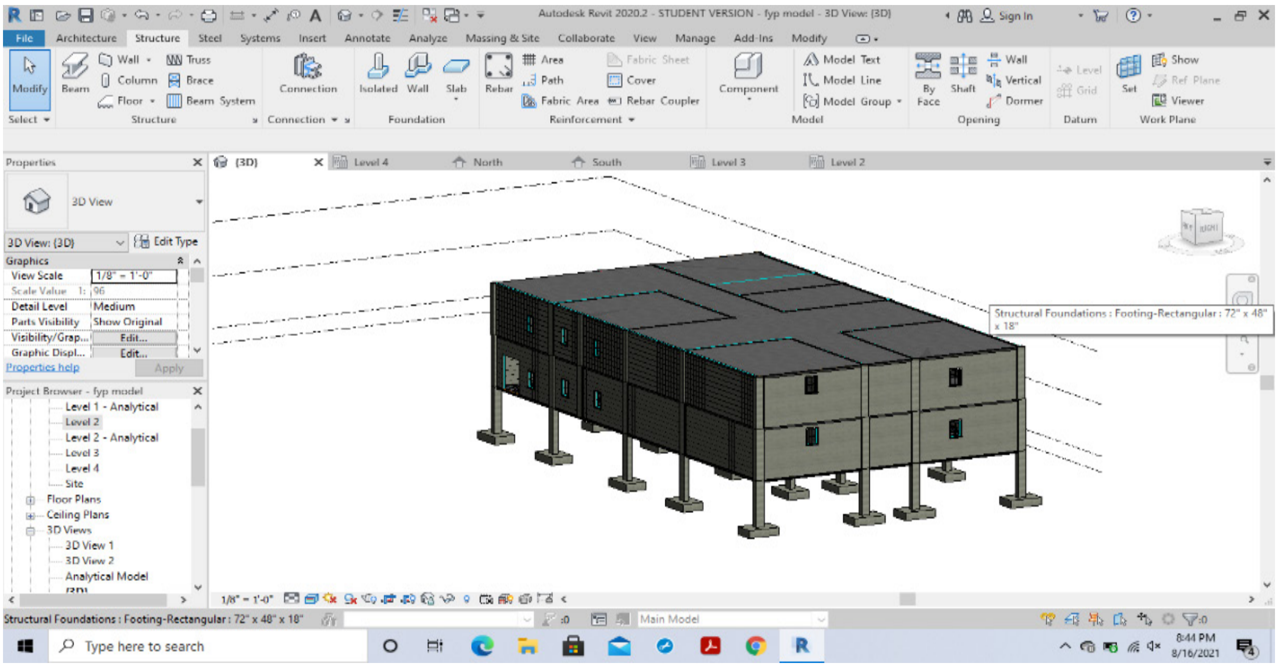

FIGURE 2. Model of the building in realistic perspective

related to construction management. The model can be seen in Figure 2 in Revit software with perspective set at realistic. Our typical structures consist of an area of six hundred square yards and construction is done on 500 square yards leaving remaining area open for lawn.

CALCULATING QUANTITIES OF MATERIAL

The quantities of material in Revit structures could be found by various methods. The method that seemed most suitable for this research was schedule and material take off. The benefit it had over quantity take off was its result was calculated for every individual component. Unlike other methods that output volume of material for the type of material, this method gives data for distinct components like columns, walls etc. The schedules, in addition give location of every component present in the model as well, providing more usable data. This type of result gives a better idea of the data for the model. It also gives location of every component in the model. The material takes-offs found in this research were of columns, walls, foundation, floor, doors, windows, and rebar. The result of material take off for the column can be seen in Figure 3. The heads of this sheet are selected by judgement to know the quantities of type of data that would be useful for the research. The volume part was of the most use to us. The software itself adds all the volume and gives us a total. A special type of schedule was required for the quantity of rebar. That requirement for different schedule was due to non-availability of rebar volume option in Revit. For the purpose special field had to be created.

The unit weight of steel per length is found as the rebar number is in our knowledge. The bar length is found for each such bar. Then the unit weight per length is multiplied with the bar length. The addition of all the rebar material is then output in the schedule. Once all the schedules were generated and the volumes of materials were found, the volumes were noted down for further use. Table 1 shows volumes (weight for rebar) of different components of the model building. These volumes are directly taken from the schedules generated in the Revit structures software.

TABLE 1. Volume/Quantity of all the components

COMPONENT	Quantity / Volume of Material Used
Column	636.33 cubic feet
Wall	5454.45 cubic feet
Foundation	864 cubic feet
Door	106.63 cubic feet
Window	26.47 cubic feet
Rebar	47780.72 pounds
Floor	6054.65 cubic feet

RUNNING THE PROGRAM

The results are found after running the program. The program which is coded in C++ language outputs us various types of estimates of waste. The software on boot asks number of components to be analysed, as can be seen in Figure 4. On selecting the number, program runs instructions on loop for as many times as stated in initial input. As can be seen in Figure. 4, 7 was entered as number of components. The software gives a list to select a particular component to add its quantity in pre-specified units. The quantity is input and gets recorded. The software repeated the process seven times as quantity for each component was input. Once all the data is input the software does calculation itself and outputs results, which can be found in Figure 5. The program has outputs total weight of each component. This gives the amount of waste that would be generated in total. The total weight of each component output can be seen in Figure 5. The software also outputs weight of each type of material that would be produced on performing this demolition. This is important in making decision of whether the material would reused/ recycled or would be disposed. The software outputs total weight of material (general), that would be produced because of this demolition. The total weight of each material generated can be seen in Table 2.

TABLE 2. Weight of several types of materials

Type of Material	Weight of Material (Pounds)
Metal (Steel)	47780.7
Concrete	2046860
Glass	4261.67
Wood	9596.7

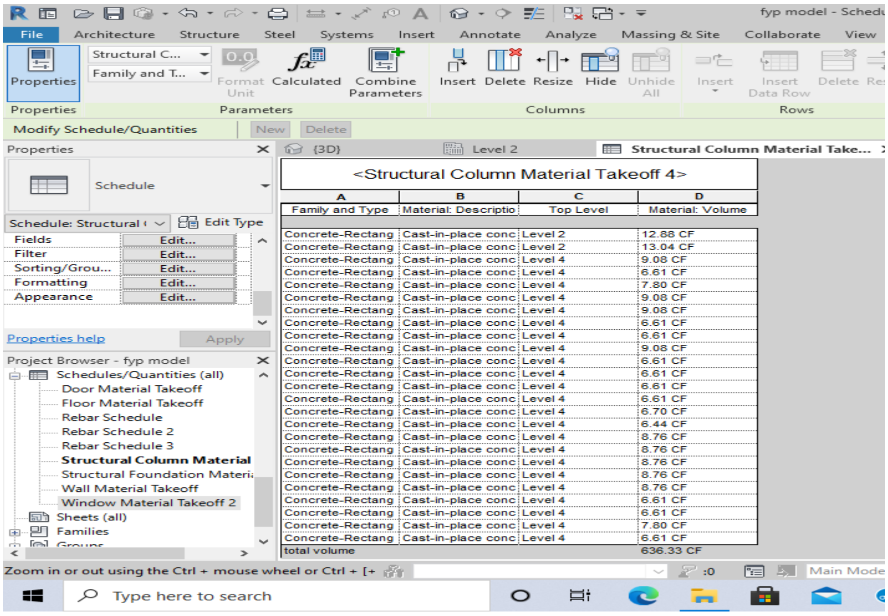

FIGURE 3. Schedule/Material take off for columns.

For efficient construction management, the software additionally outputs the amount of material that could be sent to reuse/recycle. It also states the amount to be sent to sorting and dumping facilities.

The software has done it by categorization. It sends all material but concrete and steel to sorting and dumping facilities. An additional output by the software is of finding out the number of trucks (pre-selected capacity of 4000 pounds) that would be required to transport all the cargo.

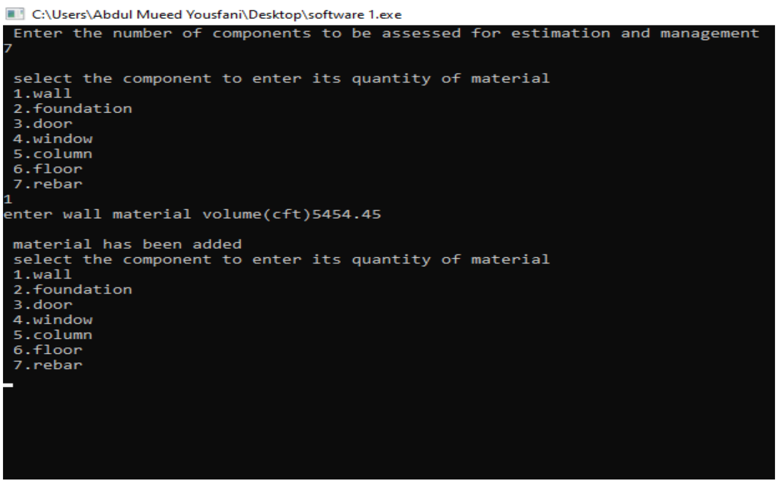

FIGURE 4. Software records volume of wall material

The material for different destinations as estimated by the program can be seen in Table 3.

TABLE 3. Weight and number of trucks of materials

Category	Weight Of Material (Kilo-Pounds)	Number Of Trucks Required (4000 Pounds Capacity)
Reuse/Recycle	2094.64	523.661 (almost 524)
Sort/Dump	13.8584	3.46459 (almost 4)

At last, the program outputs cost of all material. The significance of this output is that we get to know the amount (in PKR) that we on average would save by reusing/ recycling all this material. The output of the software for cost of all the materials that can be saved, is given in the Table 4. The results of this table are found by multiplying the quantity of each material with the per unit cost of that material. The per unit cost if found by gathering information from local market at that time.

TABLE 4. Total cost of different materials

Type of Material	Total cost (Rs)
Concrete	2428950
Metal (Steel)	3770450
Glass	18529
Wood	298564

CONCLUSION

The research ended after successfully developing the framework for effective waste estimation. The model prepared was evaluated for an example of a residential building, common in Pakistan. The framework gave results of estimate for the waste to be generated. The program that was coded, gave a partial path for construction management of the waste as well. In general, the research completed all its aim and objectives. In conclusion we may say that the research was successful and was completed with favourable results. The framework developed can be used by our agencies and institution for better estimation and management work. The research in the end did contribute to our industry. Although the research was comprehensive, and it covered various spheres. There are still features, lacking in this research. The limitations of this research are but not limited to, lot of manual input requirement. Where modern technology requires faster and less human

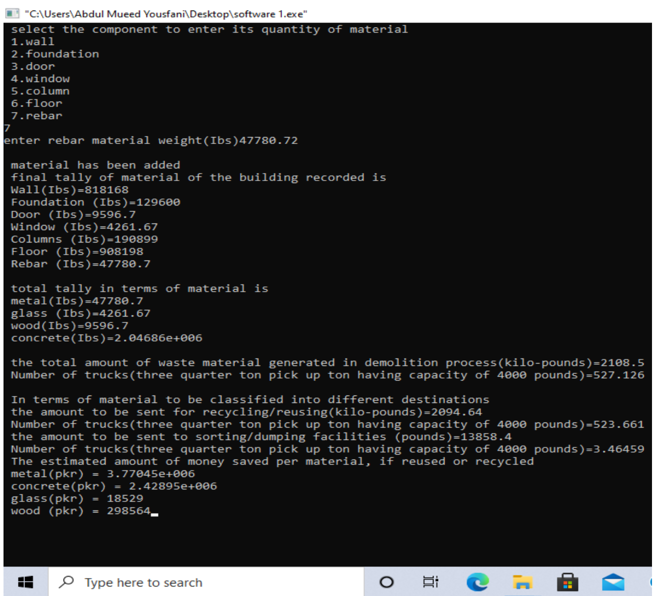

FIGURE 5. Final results from software

intensive work. This research remains backward in this area and can make use of a future research developing system that directly imports data from Revit on one click. Another good addition in future can be to cover larger commercial buildings instead of small residential building. In that way, another dimension of our cultural products could be assessed. As a better effort in this research, we can add MEP (Mechanical, Electrical and Plumbing) data in the model as well and make even better estimate of the waste that is generated in the process. Once we add MEP data as well, we would be getting estimation of waste way closer to waste produced in the field.

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DECLARATION OF COMPETING INTEREST

None

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