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## 6<sup>th</sup> North American Industrial Engineering and Operations Management Conference

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# **Control Of Rebar Waste Rate Using Building Information Modelling : A Case Study Of Suspended Road Structure**

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## **Abstract**

Rebar materials are one of the major construction materials in a construction process that generate main contribution of construction and demolition (C&D) wastage. Therefore, a monitoring and controlling process as a part of waste management in design, procurement and construction phases is obligatory. This paper presents a model for a rate calculation of rebar waste in the construction phase based on realtime progress by blending output from Building Information Modelling (BIM) Quantity Takeoff Software in the form of the report of total volume steel reinforcement and that of current rebar volume based on the existing progress to monitor spreadsheet to perform the rate calculation of real time and exact rebar waste. Simulation and “What if” scenario were applied to this proposed calculation model. For a 40% progress of the suspended road structure project, the proposed calculation model partakes 4,02% rebar waste rate. This result validates that the model can produce rebar waste rate based on the existing project progress.

**Keywords: Waste Rate, Rebar, BIM**

## **1. Introduction**

Nowadays sustainable development has become a popular topic in socio-economic development of every country. Minimizing negative impact on environment through construction industry is highly required in the global sustainable development goals. The strong ties between environmental concerns and urban development as one of the primary generators of material waste and consumers of water and energy have been recognized by government as well as construction industry professionals. This explains why the adaptation of green practices in the construction industry has been increasingly growing (Tafazzoli et al., 2020). As cited in Tafazzoli’s (year) research, green practices in construction industry focus on minimizing activities considered as waste. Minimizing waste does not only bring value for the owner, but also more profits, thus enhances the quality and improve the customer satisfaction. Construction sector is one of the major contributors to global waste generation. The impact of waste disposal pollutes the environment; therefore, a call for an improvement in the waste management is essential (Fitri et al.,2019).

The findings of Nagapan et al.’s (2012) research in Malaysia suggested 5 key causes of waste generation: poor site management and supervision; lack of experience; inadequate planning and scheduling; mistakes and errors in design; and mistakes during construction. Other researchers such as Fitri et al. (2019) listed several factors contributing to waste production: recurrent design changes; errors in design and construction detail; waste from cutting uneconomical shapes; lack of knowledge and experience in construction waste; purchase of materials which are unsuitable with the specification; and inappropriate storage causing failure and rework. This suggests that the construction stakeholders need to raise concerns about waste construction not only in a construction phase but also in a design phase and take action in minimizing the waste.

The majority of the current practices of managing construction waste focus on the construction stage. Some forecasting tools have been used to assist construction waste reduction during design stages. However, decision making tools for construction waste management during design stages are lacking (Liu et al.,2015).

Information on reliable waste generation is a basic requirement for formulating successful waste management strategies (Wu et al., 2014). According to Wu et al.’s (2014) research, generation rate calculation is the most popular methodology for estimating construction and demolition waste amounts. Some integrations of calculation method include survey visit and fixed percentage. For rebar material, fixed percentage rate estimation is quite essential in cutting down the wastage and saving money.

BIM is primarily used as a visualization tool and considered to be an interactive tool that allows efficient and dramatic productivity in project management process from produce drawing, time management, budget calculation, visualization of characteristics of the objects and full integration between stakeholders in a cloud-based environment (Zaini et al., 2020).

Recent technological development in 3D modelling has contributed to the efficiency of project design, estimation, and delivery. BIM has assisted construction industries with their development by using BIM-based quantity take off and estimation systems to minimise time-consuming processes and thorough calculations of volumes for specific materials using a traditional estimation of 2D-images (Olsen et al., 2017). BIM has become a popular and productive tool in professional construction industry due to its precision function and integration in project quantity calculation. BIM supports project stakeholders to calculate waste generation rate and make a decision mainly in the case of rebar waste management.

Prasetyo's (2020) study in Indonesia on engineering process in a project during a pandemic confirms the use of BIM for a more effective process of quantity survey calculation since it benefits the ability of the software when operated off site and from home. This suggests that the use of BIM as project tools in calculation will move a project forward and the BIM is open for further research. This research aims to propose a calculation model for rebar waste rate during the construction phase by maximizing the function and output from BIM as a baseline for waste management decision making.

## **2. Literature Review**

### *2.1. Calculation of Waste Rate*

Today, every stakeholder in the construction industry has raised their awareness to keep their production and construction process as green as possible due to their major contribution to waste generation. As cited in Masudi et al. (2011), the first step to minimize waste generation is to categorize and estimate the quantity of construction waste. Quantifying construction waste is an important part of waste management (Masudi et al., 2011).

In a study conducted by Masudi et al. (2011) in Malaysia, they found that six out of nine projects indicated that rebar has highest wastage level. Rebar material is considered as one of the five major types of building materials which can generate various types of wastes. The main causes of steel wastage include cutting, damaging, and rusting during storage (Tam et al., 2007). Since rebar offers numerous approaches to generate waste and has high wastage level in project construction, project stakeholders need to consider rebar waste rate to be precisely quantified.

Some research about waste rate calculation retrieved. A case study of construction waste quantification in Netherland by Bossink et al. (1996) reported that resulted waste rate as percentage of total amount of construction waste, percentage of purchased amount of specific construction material and percentage of total waste costs. The main contributors of waste are stone tablets (Bossink et al., 1996).

Parisi Kern et al. (2015) deployed multiple linear regressions to analyze the amount of waste generated in 18 residential high-rise building constructions. Among the tested variables, those that showed influence on waste generation were number of floors, waste reuse or recovery category, floor plan compactness, construction system and apartment floor plan areas. The set of variables was able to predict approximately 69% of the factors involved in the waste generation in high-rise buildings (Parisi Kern et al., 2015). This paper evaluate wastage generation rate of constructed buildings.

Masudi et al. (2011) exploited calculation of wastage level from total order quantities for various materials. Ding et al. (2014) calculate the total weight of building-related constructions and demolition waste generation during one year, where they calculate waste as a whole general process rather than project based.

Design stages have a greater opportunity for reducing rebar waste, but design changes during construction stage can lead to major generation waste, so a precise, effective and quick technique to quantify rebar waste rate during construction stage is considered a baseline for decision making in waste management.

### *2.2. BIM-based quantity takeoff in practice*

Liu et al. (2015) found correlation between the causes of construction waste during each design stage and BIM potential for improving construction waste management, leading to the development of the BIM-enhanced-design-related activities for reducing construction waste generation, BIM for addressing construction waste causes, and BIM potential for construction waste management in line with current architects practices of BIM-assisted energy efficiency throughout building design stages.

BIM has been implemented over the last five years in the construction industry. According to Olsen et al.s' (2017) study, one hundred percent of their respondents used BIM for quantity take-off. The authors' data were collected through interviewing stakeholders in 14 large construction companies located in the Southeastern U.S with annual revenues at least \$500 million per year (Olsen et al., 2017). The finding of the study suggested that BIM-based estimating is reliable for the US large construction companies that offer advantages in their industry processes mainly at project visualization and processing data speed.

Quantity takeoff is the foundation for other tasks in the construction management to perform cost estimation and schedule planning. Traditionally, quantity takeoff is a manual process during which quantities of design elements are measured based on 2D or 3D drawings. BIM offers the best automatic approach to generate accurate quantity takeoff directly from 3D models (Liu et al., 2014)

BIM identification means identifying exactly which element in a building is owned by which properties, which will then help constructors make precise and accurate calculations for each specific building. This is suitable with the estimation of individual features such as construction waste sizes (Koutamanis, 2020)

Cubicost is one of the BIM software quantity take off. They have a specific function to calculate the quantity of rebar in a quick fashion (Anindya et al., 2020). Anindya et al. (2020) found that Cubicost had a 58% productivity increase compared to a conventional method.

### **3. Methodology**

The concept of this proposed model is to amalgamate the practice of the rebar waste rate calculation with BIM software output as a part of calculation input. The idea is to get rebar waste rate in a more productive and quicker approach since BIM has a software implementation in itself. A deep interview with a field project team and literature review were conducted to explore the usual and productive approach to calculate rebar waste rate in the construction phase.

#### *3.1. Waste Rate Calculation*

Prior studies have applied waste rate quantity calculation. For example, Masudi et al. (2011) employed various sites in Klang Valley, Malaysia, where they calculated the wastage level (4) by calculating the deviation of cumulative order quantity (1) and cumulative workdone (2) divided by cumulative workdone (2). The formula is:

$$(4) \text{ Wastage Level} = \frac{(1) \sum \text{Order Quantity} - (2) \sum \text{Workdone}}{(2) \sum \text{Workdone}}$$

The construction waste generation estimation also can be calculated based on sequential sections of building construction as determined in the schedule (Guerra et al, 2020). The formula is as follows (5) :

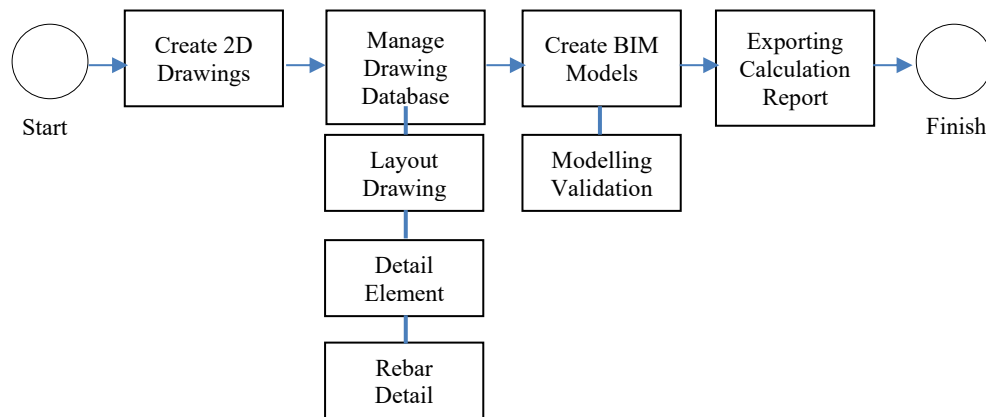
$$(5) \text{ Construction Waste (at "n" sections)} = \sum \text{Purchased}(n \text{ section}) - \sum \text{Needed}(n \text{ section})$$

Interviews were performed with engineering and logistics staff from state-owned contractors described needed variables and formula to calculate rebar waste rate (6). The difference between formula number 4 and number 5 is that they divide sum of rebar workdone with sum of rebar stated in contract ( $VpI$ ).

$$(6) \text{ Waste Rate (\%)} = \frac{\sum V_{purchased}(Vp) - \sum V_{installed}(Vi) - \sum V_{stock}(Vs) - \sum V_{fabricated}(Vf)}{\sum V_{purchased}(Vp1)}$$

#### *3.2. BIM Workflow for Quantity Takeoff*

In Anindya et al (2020) paper, retrieved a BIM quantity takeoff workflow using Cubicost software. The workflow starts with compiling the database such as 2D drawings, specification, and rebar calculation rule. The next step is to create 3D models by compiling it with rebar detail databases and calculate the 3D models. The outputs from this workflow are visualization of building model and quantity report as presented in our proposed model below.



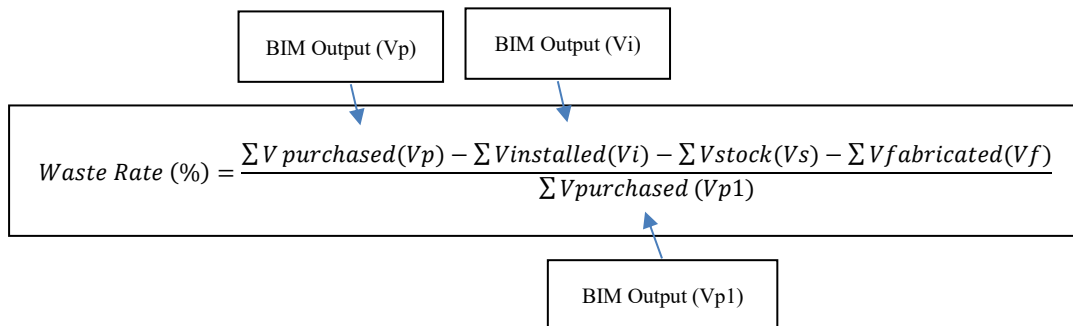
**Figure 3.1** BIM Workflow for Quantity Take Off

### 3.3. Collaborative Calculation Model

Figure 3.2 shows the idea of proposed calculation model. It compiled a calculation method from Masudi et al (2011) and Guerra et al (2021). These authors calculate the waste rate based on summary of workdone.

The interview resulted in more accurate calculation of waste rate since they made a summary of purchased ( $V_p$ ) material as baseline and also calculated the summary of stocked ( $V_s$ ) and fabricated ( $V_f$ ) material.  $V_s$  and  $V_p$  value also are possible to control and calculate with high accuracy with the help of documentation control when worker aspired to perform rebar fabrication.

Value of installed ( $V_i$ ) material will be taken out by maximizing BIM function. It calculates the rebar volume in quick way based on existing project progress and it can be monitored realtime every day whenever project team intended to evaluate realtime waste rate.



**Figure 3.2** Rebar Waste Rate Proposed Calculation Model

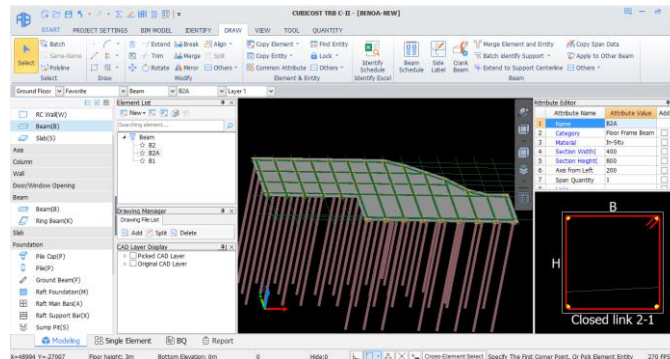
## 4. Case Study

The calculation model is simulated in a suspended road project. The structure elements in this project are pile cap, tie beam, and slab. BIM Software had limitations in calculating pile elements so in this case study, pile volume calculations are excluded.

### 4.1. Preliminary BIM Workflow

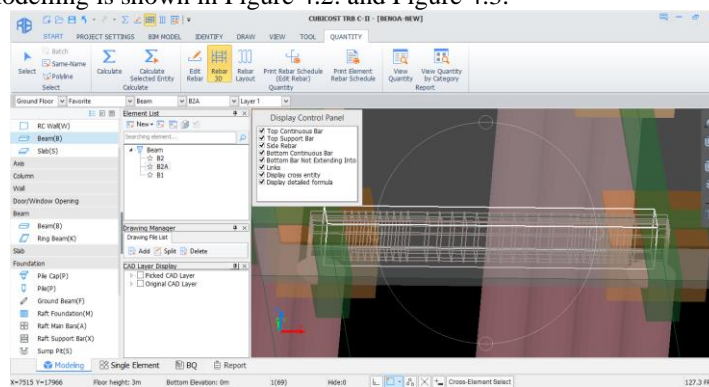
To calculate the existing rebar waste rate, three steps need to be followed, the first stage modelling requirements are :

1. 2D drawings layout and structure element detail of the project then they are modelled into BIM software as an input for BIM Modelling. The result of the whole project modelling is shown in Figure 4.1. The aim of this step is to determined the exact dimension and visualization of the whole project.

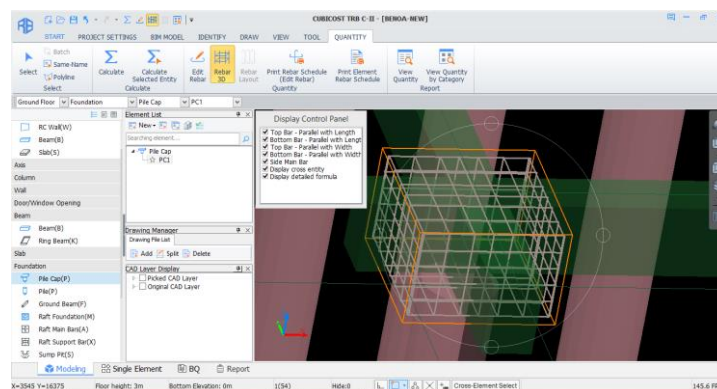


**Figure 4.1** Generated BIM Models

2. After BIM model had been determined, check the modelling and validate every structure element through 3D rebar view to make sure that the modelling represents the exact rebar needs and shape. The validation process of rebar modelling is shown in Figure 4.2. and Figure 4.3.



**Figure 4.2** Validation of Beam Element Rebar Modelling



**Figure 4.3** Validation of Pile Cap Element Rebar Modelling

3. After all of the structure element had been validated, run the BIM model calculation to get the volume report. The output of calculation report can be exported into spreadsheet file (Excel file).

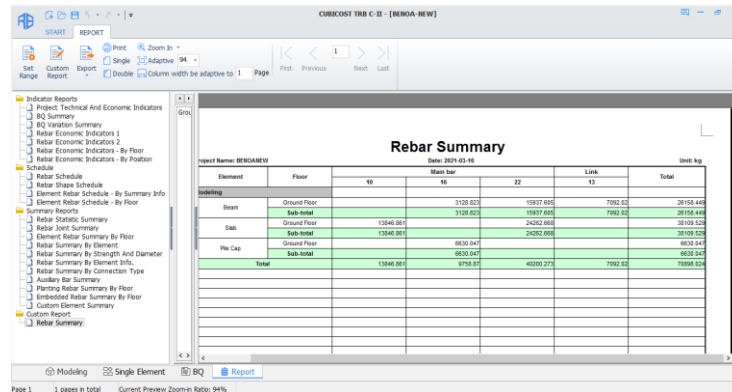


Figure 4.4 Total Rebar Volume Calculation Report

The outputs of these three process are fundamentals because it becomes the input for the next step to calculate rebar waste rate. The whole rebar volume report in this project is a baseline for rebar purchasing and procurement plan, so for the next step we already got the  $V_p$  value.

#### 4.2. Realtime of BIM Calculation

The next step is to make a BIM model based on existing work progress of the project and take off the quantity. In this case study, the simulation of the project progress are in 40%.

The workflow in this step is shown in Figure 4.5, where the 2D layout drawings needed in workflow are based on existing project progress. This modelling has limitations where the concrete edge of the latest project progress can't determine the length of the rebar lap; hence, in this modelling the length of the rebar lap is excluded and not calculated.

The workflow for modelling and calculating existing project rebar volume are the same with the previous workflow. The existing progress modelling shown in Figure 4.6 , and the rebar volume report from existing progress modelling ( $V_i$ ) shown in Figure 4.7

From this step we already have  $V_p$  and  $V_i$  as an input for rebar waste calculation.

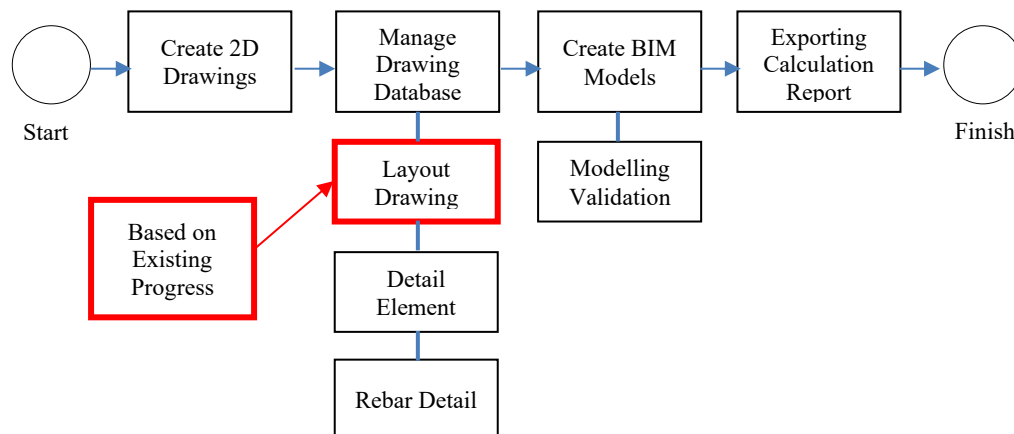


Figure 4.5 BIM Workflow for Quantity Take Off Existing Project Progress



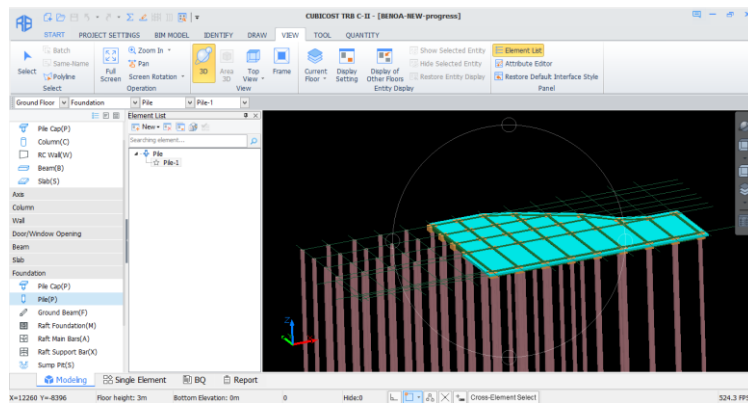


Figure 4.6 Existing Progress BIM Models

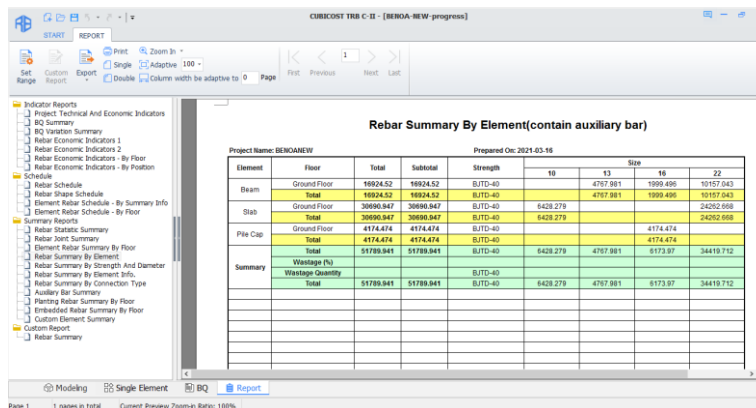


Figure 4.7 Existing Progress Rebar Volume Calculation Report

#### 4.3. Spreadsheet Collaboration with BIM Report

The Vp and Vi data obtained from the modelling are shown in Table 4.1 and Table 4.2. Then Vp and Vi data in spreadsheet are merged for the calculation of the rebar waste rate. Spreadsheet calculation entails simulation of the existing progress of the project where in this case the rebar stock volume (Vs) and the fabricated rebar volume need to be recorded whether they are bars or main rebar (Vf). For real time purposes, the Vs and Vf values require a manual calculation and documentation due to their simplicity counting and visual monitoring related matters.

Of the 40% of the project progress, we found that the total of Vs value is 5.000 kg, where it consists of various diameters and the total of Vf value is 800 kg where the main fabricated rebar are in shape of bars. After all of the input values had been determined, next step is calculating the rebar waste rate with rebar waste rate formula. The simulation of rebar waste rate of the 40% project progress in spreadsheet results in 4,02% of waste rate of rebar.

Table 4.1 Total Rebar Volume Calculation Report

Element	Total	Size			
		10	13	16	22
BEAM	26,158		7,092.02	3,128.82	15,937.61
SLAB	38,110	13,846.86			24,262.67
PILECAP	6,630			6,630.05	
<b>Summary</b>	<b>70,898</b>	13,846.86	7,092.02	9,758.87	40,200.27

\*Assume 60,000 kg of rebar already purchased by logistics

Table 4.2 Existing Progress Rebar Volume Calculation Report

Element	Total	Size			
		10	13	16	22
BEAM	<b>16,924.52</b>		4767.981	1999.496	10157.043
SLAB	<b>30,690.947</b>	6428.279			24262.668
PILECAP	<b>4,174.474</b>			4174.474	
<b>Summary</b>	<b>51,789.941</b>	6,428.28	4,767.98	6,173.97	34,419.71

<b>a</b>	V purchased	60,000.00 kg
<b>b</b>	V installed	51,789.94 kg
<b>c</b>	V stock	5,000.00 kg
<b>d</b>	V fabricated	800.00 kg
		2,410.06 kg
	Waste Rate =	<b>(a-b-c-d)/a %</b>
		<b>4.02%</b>

## 5. Conclusion

The objective of this paper was to extend BIM function as waste management collaborative tools for rebar waste control and management in construction phase.

Generally, the proposed model of calculation is successful and validated by a case study. The model was effective in providing the calculation of the real time rebar waste rate so the project team could monitor and control waste rate in the field. This proposed calculation model also offers the stakeholders more options and assistance in decision making processes and evaluating the rebar production in more productive and quick manners through BIM, especially for a crash program project with no detailed plan on rebar shape schedule.

The present study, however, was unable to calculate the length of extended rebar lap in the edge of latest concrete that makes the model a little less accurate. This study may be applicable to a single floor infrastructure; thus, a further study could develop the proposed model in more complex types of constructions such as building constructions.

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## Biographies

**Ryan Faza Prasetyo** is a young construction management lecturer in Civil Engineering & Planning Faculty in Trisakti University, Jakarta. Earned bachelor degree in Institut Teknologi Sepuluh Nopember Surabaya, Indonesia (ITS) in 2013 and master degree in same institute in 2015. Before join lecturing team in Trisakti University, he spent 6 years' experience in state-owned contractor company with speciality in commercial building project. His research interest include project operational, value engineering, optimization, automation, BIM implementation and sustainability.

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# **Control Of Rebar Waste Rate Using Building Information Modelling : A Case Study Of Suspended Road Structure**

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## **Abstract**

Rebar materials are one of the major construction materials in a construction process that generate main contribution of construction and demolition (C&D) wastage. Therefore, a monitoring and controlling process as a part of waste management in design, procurement and construction phases is obligatory. This paper presents a model for a rate calculation of rebar waste in the construction phase based on realtime progress by blending output from Building Information Modelling (BIM) Quantity Takeoff Software in the form of the report of total volume steel reinforcement and that of current rebar volume based on the existing progress to monitor spreadsheet to perform the rate calculation of real time and exact rebar waste. Simulation and "What if" scenario were applied to this proposed calculation model. For a 40% progress of the suspended road structure project, the proposed calculation model partakes 4,02% rebar waste rate. This result validates that the model can produce rebar waste rate based on the existing project progress.

**Keywords: Waste Rate, Rebar, BIM**

## **1. Introduction**

Nowadays sustainable development has become a popular topic in socio-economic development of every country. Minimizing negative impact on environment through construction industry is highly required in the global sustainable development goals. The strong ties between environmental concerns and urban development as one of the primary generators of material waste and consumers of water and energy have been recognized by government as well as construction industry professionals. This explains why the adaptation of green practices in the construction industry has been increasingly growing (Tafazzoli et al., 2020). As cited in Tafazzoli's (year) research, green practices in construction industry focus on minimizing activities considered as waste. Minimizing waste does not only bring value for the owner, but also more profits, thus enhances the quality and improve the customer satisfaction. Construction sector is one of the major contributors to global waste generation. The impact of waste disposal pollutes the environment; therefore, a call for an improvement in the waste management is essential (Fitri et al., 2019).

The findings of Nagapan et al.'s (2012) research in Malaysia suggested 5 key causes of waste generation: poor site management and supervision; lack of experience; inadequate planning and scheduling; mistakes and errors in design; and mistakes during construction. Other researchers such as Fitri et al. (2019) listed several factors contributing to waste production: recurrent design changes; errors in design and construction detail; waste from cutting uneconomical shapes; lack of knowledge and experience in construction waste; purchase of materials which are unsuitable with the specification; and inappropriate storage causing failure and rework. This suggests that the construction stakeholders need to raise concerns about waste construction not only in a construction phase but also in a design phase and take action in minimizing the waste.

The majority of the current practices of managing construction waste focus on the construction stage. Some forecasting tools have been used to assist construction waste reduction during design stages. However, decision making tools for construction waste management during design stages are lacking (Liu et al., 2015).

Information on reliable waste generation is a basic requirement for formulating successful waste management strategies (Wu et al., 2014). According to Wu et al.'s (2014) research, generation rate calculation is the most popular methodology for estimating construction and demolition waste amounts. Some integrations of calculation method include survey visit and fixed percentage. For rebar material, fixed percentage rate estimation is quite essential in cutting down the wastage and saving money.

BIM is primarily used as a visualization tool and considered to be an interactive tool that allows efficient and dramatic productivity in project management process from produce drawing, time management, budget calculation, visualization of characteristics of the objects and full integration between stakeholders in a cloud-based environment (Zaini et al., 2020).

Recent technological development in 3D modelling has contributed to the efficiency of project design, estimation, and delivery. BIM has assisted construction industries with their development by using BIM-based quantity take off and estimation systems to minimise time-consuming processes and thorough calculations of volumes for specific materials using a traditional estimation of 2D-images (Olsen et al., 2017). BIM has become a popular and productive tool in professional construction industry due to its precision function and integration in project quantity calculation. BIM supports project stakeholders to calculate waste generation rate and make a decision mainly in the case of rebar waste management.

Prasetyo's (2020) study in Indonesia on engineering process in a project during a pandemic confirms the use of BIM for a more effective process of quantity survey calculation since it benefits the ability of the software when operated off site and from home. This suggests that the use of BIM as project tools in calculation will move a project forward and the BIM is open for further research. This research aims to propose a calculation model for rebar waste rate during the construction phase by maximizing the function and output from BIM as a baseline for waste management decision making.

## **2. Literature Review**

### *2.1. Calculation of Waste Rate*

Today, every stakeholder in the construction industry has raised their awareness to keep their production and construction process as green as possible due to their major contribution to waste generation. As cited in Masudi et al. (2011), the first step to minimize waste generation is to categorize and estimate the quantity of construction waste. Quantifying construction waste is an important part of waste management (Masudi et al., 2011).

In a study conducted by Masudi et al. (2011) in Malaysia, they found that six out of nine projects indicated that rebar has highest wastage level. Rebar material is considered as one of the five major types of building materials which can generate various types of wastes. The main causes of steel wastage include cutting, damaging, and rusting during storage (Tam et al., 2007). Since rebar offers numerous approaches to generate waste and has high wastage level in project construction, project stakeholders need to consider rebar waste rate to be precisely quantified.

Some research about waste rate calculation retrieved. A case study of construction waste quantification in Netherland by Bossink et al. (1996) reported that resulted waste rate as percentage of total amount of construction waste, percentage of purchased amount of specific construction material and percentage of total waste costs. The main contributors of waste are stone tablets (Bossink et al., 1996).

Parisi Kern et al. (2015) deployed multiple linear regressions to analyze the amount of waste generated in 18 residential high-rise building constructions. Among the tested variables, those that showed influence on waste generation were number of floors, waste reuse or recovery category, floor plan compactness, construction system and apartment floor plan areas. The set of variables was able to predict approximately 69% of the factors involved in the waste generation in high-rise buildings (Parisi Kern et al., 2015). This paper evaluate wastage generation rate of constructed buildings.

Masudi et al. (2011) exploited calculation of wastage level from total order quantities for various materials. Ding et al. (2014) calculate the total weight of building-related constructions and demolition waste generation during one year, where they calculate waste as a whole general process rather than project based.

Design stages have a greater opportunity for reducing rebar waste, but design changes during construction stage can lead to major generation waste, so a precise, effective and quick technique to quantify rebar waste rate during construction stage is considered a baseline for decision making in waste management.

### *2.2. BIM-based quantity takeoff in practice*

Liu et al. (2015) found correlation between the causes of construction waste during each design stage and BIM potential for improving construction waste management, leading to the development of the BIM-enhanced-design-related activities for reducing construction waste generation, BIM for addressing construction waste causes, and BIM potential for construction waste management in line with current architects practices of BIM-assisted energy efficiency throughout building design stages.

BIM has been implemented over the last five years in the construction industry. According to Olsen et al.'s (2017) study, one hundred percent of their respondents used BIM for quantity take-off. The authors' data were collected through interviewing stakeholders in 14 large construction companies located in the Southeastern U.S with annual revenues at least \$500 million per year (Olsen et al., 2017). The finding of the study suggested that BIM-based estimating is reliable for the US large construction companies that offer advantages in their industry processes mainly at project visualization and processing data speed.

Quantity takeoff is the foundation for other tasks in the construction management to perform cost estimation and schedule planning. Traditionally, quantity takeoff is a manual process during which quantities of design elements are measured based on 2D or 3D drawings. BIM offers the best automatic approach to generate accurate quantity takeoff directly from 3D models (Liu et al., 2014)

BIM identification means identifying exactly which element in a building is owned by which properties, which will then help constructors make precise and accurate calculations for each specific building. This is suitable with the estimation of individual features such as construction waste sizes (Koutamanis, 2020)

Cubicost is one of the BIM software quantity take off. They have a specific function to calculate the quantity of rebar in a quick fashion (Anindya et al., 2020). Anindya et al. (2020) found that Cubicost had a 58% productivity increase compared to a conventional method.

### **3. Methodology**

The concept of this proposed model is to amalgamate the practice of the rebar waste rate calculation with BIM software output as a part of calculation input. The idea is to get rebar waste rate in a more productive and quicker approach since BIM has a software implementation in itself. A deep interview with a field project team and literature review were conducted to explore the usual and productive approach to calculate rebar waste rate in the construction phase.

#### *3.1. Waste Rate Calculation*

Prior studies have applied waste rate quantity calculation. For example, Masudi et al. (2011) employed various sites in Klang Valley, Malaysia, where they calculated the wastage level (4) by calculating the deviation of cumulative order quantity (1) and cumulative workdone (2) divided by cumulative workdone (2). The formula is:

$$(4) \text{ Wastage Level} = \frac{(1) \sum \text{Order Quantity} - (2) \sum \text{Workdone}}{(2) \sum \text{Workdone}}$$

The construction waste generation estimation also can be calculated based on sequential sections of building construction as determined in the schedule (Guerra et al, 2020). The formula is as follows (5) :

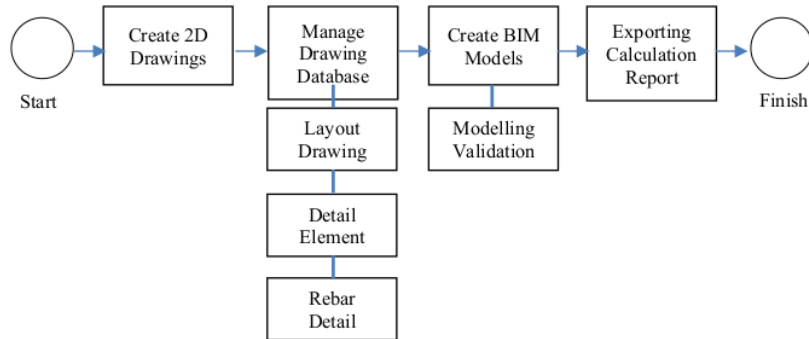
$$(5) \text{ Construction Waste (at "n" sections)} = \sum \text{Purchased}(n \text{ section}) - \sum \text{Needed}(n \text{ section})$$

Interviews were performed with engineering and logistics staff from state-owned contractors described needed variables and formula to calculate rebar waste rate (6). The difference between formula number 4 and number 5 is that they divide sum of rebar workdone with sum of rebar stated in contract ( $Vp1$ ).

$$(6) \text{ Waste Rate (\%)} = \frac{\sum V_{purchased}(Vp) - \sum V_{installed}(Vi) - \sum V_{stock}(Vs) - \sum V_{fabricated}(Vf)}{\sum V_{purchased}(Vp1)}$$

#### *3.2. BIM Workflow for Quantity Takeoff*

In Anindya et al (2020) paper, retrieved a BIM quantity takeoff workflow using Cubicost software. The workflow starts with compiling the database such as 2D drawings, specification, and rebar calculation rule. The next step is to create 3D models by compiling it with rebar detail databases and calculate the 3D models. The outputs from this workflow are visualization of building model and quantity report as presented in our proposed model below.



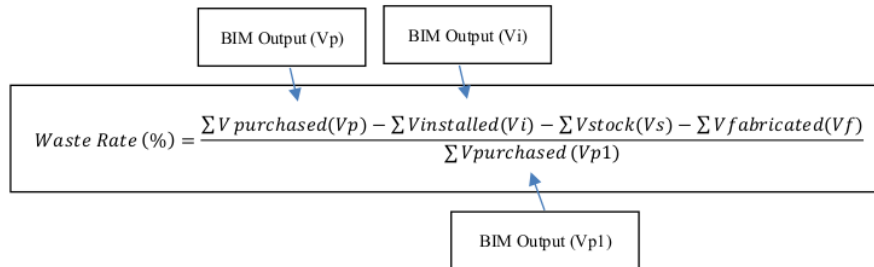
**Figure 3.1** BIM Workflow for Quantity Take Off

### 3.3. Collaborative Calculation Model

Figure 3.2 shows the idea of proposed calculation model. It compiled a calculation method from Masudi et al (2011) and Guerra et al (2021). These authors calculate the waste rate based on summary of workdone.

The interview resulted in more accurate calculation of waste rate since they made a summary of purchased (Vp) material as baseline and also calculated the summary of stocked (Vs) and fabricated (Vf) material. Vs and Vp value also are possible to control and calculate with high accuracy with the help of documentation control when worker aspired to perform rebar fabrication.

Value of installed (Vi) material will be taken out by maximizing BIM function. It calculates the rebar volume in quick way based on existing project progress and it can be monitored realtime every day whenever project team intended to evaluate realtime waste rate.



**Figure 3.2** Rebar Waste Rate Proposed Calculation Model

## 4. Case Study

The calculation model is simulated in a suspended road project. The structure elements in this project are pile cap, tie beam, and slab. BIM Software had limitations in calculating pile elements so in this case study, pile volume calculations are excluded.

### 4.1. Preliminary BIM Workflow

To calculate the existing rebar waste rate, three steps need to be followed, the first stage modelling requirements are :

1. 2D drawings layout and structure element detail of the project then they are modelled into BIM software as an input for BIM Modelling. The result of the whole project modelling is shown in Figure 4.1. The aim of this step is to determined the exact dimension and visualization of the whole project.





**Rebar Summary**  
 Report Name: REBAR0001 Date: 2021-01-05

Rebar Type	Floor	W	H	L	Vol	Wt
Beam	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00
Slab	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00
Col	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00
Wall	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00
Stair	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00
Sum	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00
Subtotal	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00
Total	Ground Floor	1121.00	1007.00	1962.00	2016.00	2016.00

Figure 4.4 Total Rebar Volume Calculation Report

The outputs of these three process are fundamentals because it becomes the input for the next step to calculate rebar waste rate. The whole rebar volume report in this project is a baseline for rebar purchasing and procurement plan, so for the next step we already got the  $V_p$  value.

4.2. Realtime of BIM Calculation

The next step is to make a BIM model based on existing work progress of the project and take off the quantity. In this case study, the simulation of the project progress are in 40%.

The workflow in this step is shown in Figure 4.5, where the 2D layout drawings needed in workflow are based on existing project progress. This modelling has limitations where the concrete edge of the latest project progress can't determine the length of the rebar lap; hence, in this modelling the length of the rebar lap is excluded and not calculated.

The workflow for modelling and calculating existing project rebar volume are the same with the previous workflow. The existing progress modelling shown in Figure 4.6 , and the rebar volume report from existing progress modelling ( $V_i$ ) shown in Figure 4.7

From this step we already have  $V_p$  and  $V_i$  as an input for rebar waste calculation.

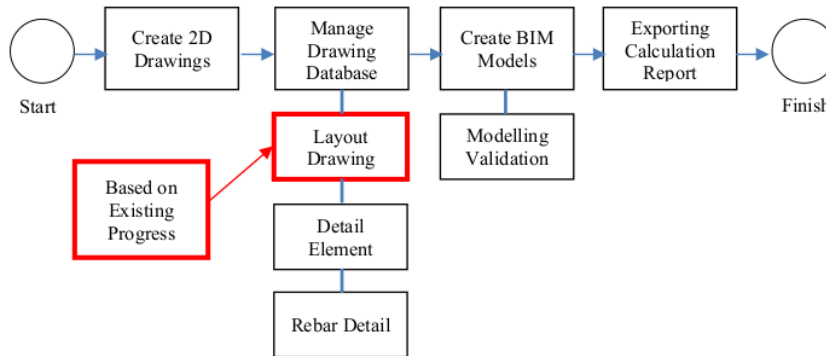


Figure 4.5 BIM Workflow for Quantity Take Off Existing Project Progress

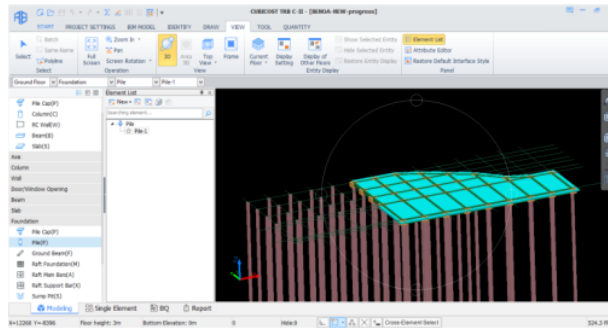


Figure 4.6 Existing Progress BIM Models

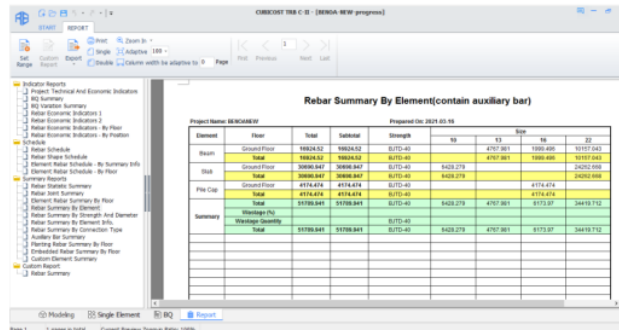


Figure 4.7 Existing Progress Rebar Volume Calculation Report

#### 4.3. Spreadsheet Collaboration with BIM Report

The Vp and Vi data obtained from the modelling are shown in Table 4.1 and Table 4.2. Then Vp and Vi data in spreadsheet are merged for the calculation of the rebar waste rate. Spreadsheet calculation entails simulation of the existing progress of the project where in this case the rebar stock volume (Vs) and the fabricated rebar volume need to be recorded whether they are bars or main rebar (Vf). For real time purposes, the Vs and Vf values require a manual calculation and documentation due to their simplicity counting and visual monitoring related matters.

Of the 40% of the project progress, we found that the total of Vs value is 5,000 kg, where it consists of various diameters and the total of Vf value is 800 kg where the main fabricated rebar are in shape of bars. After all of the input values had been determined, next step is calculating the rebar waste rate with rebar waste rate formula. The simulation of rebar waste rate of the 40% project progress in spreadsheet results in 4,02% of waste rate of rebar.

Table 4.1 Total Rebar Volume Calculation Report

Element	Total	Size			
		10	13	16	22
BEAM	26,158		7,092.02	3,128.82	15,937.61
SLAB	38,110	13,846.86			24,262.67
PILECAP	6,630			6,630.05	
<b>Summary</b>	<b>70,898</b>	13,846.86	7,092.02	9,758.87	40,200.27

\*Assume 60,000 kg of rebar already purchased by logistics

Table 4.2 Existing Progress Rebar Volume Calculation Report

Element	Total	Size			
		10	13	16	22
BEAM	<b>16,924.52</b>		4767.981	1999.496	10157.043
SLAB	<b>30,690.947</b>	6428.279			24262.668
PILECAP	<b>4,174.474</b>			4174.474	
<b>Summary</b>	<b>51,789.941</b>	6,428.28	4,767.98	6,173.97	34,419.71

<b>a</b>	V purchased	60,000.00 kg
<b>b</b>	V installed	51,789.94 kg
<b>c</b>	V stock	5,000.00 kg
<b>d</b>	V fabricated	800.00 kg
		<u>2,410.06 kg</u>
Waste Rate =		<b>(a-b-c-d)/a %</b>
		<b>4.02%</b>

## 5. Conclusion

The objective of this paper was to extend BIM function as waste management collaborative tools for rebar waste control and management in construction phase.

Generally, the proposed model of calculation is successful and validated by a case study. The model was effective in providing the calculation of the real time rebar waste rate so the project team could monitor and control waste rate in the field. This proposed calculation model also offers the stakeholders more options and assistance in decision making processes and evaluating the rebar production in more productive and quick manners through BIM, especially for a crash program project with no detailed plan on rebar shape schedule.

The present study, however, was unable to calculate the length of extended rebar lap in the edge of latest concrete that makes the model a little less accurate. This study may be applicable to a single floor infrastructure; thus, a further study could develop the proposed model in more complex types of constructions such as building constructions.

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## Biographies

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