QUANTIFICATION OF CONSTRUCTION WASTE USING DIGITAL IMAGES

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ผลที่ได้จากการดำเนินงานในอุตสาหกรรมก่อสร้างนั้น ไม่ใช่เฉพาะองค์อาคารหรือสาธารณูปโภค แต่รวมถึงเศษวัสดุต่างๆ จากการดำเนินการกิจกรรมก่อสร้าง โดยเศษวัสดุเหล่านั้นก่อให้เกิดผลกระทบทางสิ่งแวดล้อม ในปัจจุบันยังขาดการให้ความสำคัญต่อการจัดการเศษวัสดุอย่างจริงจัง ปริมาณเศษวัสดุที่เกิดขึ้นสามารถทราบได้จากจำนวนรถบรรทุกที่ทำการขนย้ายเศษวัสดุออกจากหน่วยงานก่อสร้างไปยังพื้นที่กองขยะ อย่างไรก็ตามนักสิ่งแวดล้อมต้องการทราบปริมาณเศษวัสดุเพื่อใช้ในการจัดการผลกระทบต่อสิ่งแวดล้อม แต่โครงการไม่มีวิธีการหรือเครื่องมือที่สะดวกต่อการใช้ในการหาปริมาณขยะที่เกิดขึ้นในแต่ละวัน หรือเดือน และปริมาณเศษวัสดุที่เกิดขึ้นในหลายๆ ที่ของโครงการก่อสร้างอาคารที่มีจำนวนหลายชั้น งานวิจัยนี้นำเสนอวิธีในการกำหนดปริมาณวัสดุในเชิงปริมาตรและน้ำหนักโดยใช้ภาพดิจิตอล ระบบที่พัฒนาขึ้นถูกออกแบบเป็น 3 ส่วน คือ การรวบรวมภาพ การส่งผ่านข้อมูล และการวิเคราะห์ภาพ ระบบในงานวิจัยถูกดำเนินการผ่านการวิจัยเบื้องต้น การพัฒนาและออกแบบระบบ การทดสอบเครื่องมือต้นแบบ การนำไปใช้และการทดสอบความเที่ยงตรง ซึ่งระบบที่ถูกพัฒนาขึ้นนี้นำเสนอวิธีในการหาปริมาณเศษวัสดุจำนวน 2 วิธีตามพื้นฐานของวัตถุในภาพที่นำมาใช้ คือ วัตถุดั้งเดิมหรือวิธีภาพปกติ และวัตถุที่มีการปรับแต่งหรือวิธีปรับโครงร่างให้เรียบ การทดสอบความเที่ยงตรงถูกนำมาใช้เพื่อทดสอบระบบโดยเปรียบเทียบกับปริมาตรของรถบรรทุกและการชั่งน้ำหนักของเศษวัสดุ จากการวิเคราะห์ระบบโดยใช้ 95 % ของช่วงข้อมูลที่ตกลง พบว่า การหาปริมาตรของเศษวัสดุ หน่วยเป็น ลูกบาศก์เมตร มีระดับความเชื่อมั่นที่ 60 % และการหาน้ำหนักของเศษวัสดุ หน่วยเป็นกิโลกรัม มีระดับความเชื่อมั่นที่ 70 % ในอนาคต ประโยชน์จากระบบที่พัฒนาขึ้นนี้ทำให้การหาปริมาณเศษวัสดุ สะดวก รวดเร็วยิ่งขึ้น และสามารถสนับสนุนข้อมูลสำหรับนักสิ่งแวดล้อมในการจัดการความจุของพื้นที่กองขยะ

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Construction industry produces not only buildings/ infrastructures but also construction waste. In addition, construction waste contributes to the environment disruption. However, there is less attention to proper waste management at the construction sites. The quantity of waste is known from the number of trucks carrying waste from the site to landfill. On the other hand, an environmentalist requires the information of construction waste to manage the environmental impact. There is no easy-to-use tool or method to quantify the waste production at daily or monthly, basis and the waste production at various places in the multi-storey building construction. This research proposes an alternative method for waste quantification in terms of volume and weight based on digital images. The quantification system consists of three modules; image acquisition, data transfer and image analysis. To obtain the objective, the research was done by pilot research, system design and development, prototype testing, implementation and validation at the construction site. The quantification system offered two approaches based on the simple image and the modified image. The validation of quantification system was compared with the truck capacity and the weight measurement at a weighbridge. The analysis using the 95% limit of agreement showed the level of confidence was about 60 % for volume (in cubic meter) and 70% for weight (in kilogram). The system provides an ease to use for quantifying construction waste at construction site.

Department : Civil Engineering	Student's Signature ....
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CHAPTER I
INTRODUCTION

Chapter 1 provides an overview of the dissertation, consisting of research background, statements of problems, research objectives, scopes of research, research methodology and research contributions. The first chapter introduces the importance of research and the current state of construction waste quantification at the construction site.

1.1 Background

Some activities in a construction project are not environment friendly. The exploration of natural resources to procure the natural materials of construction has been done by human since long time ago. The explorations of forests, river and mountain are activities in order to obtain the basic materials, which are increasing year by year. Consumption of virgin wood and aggregates in construction industry is about 25 % and 40% yearly (Hobbs, G., and Hurley, J., 2001).

Construction activities produce two types of products; buildings or infrastructure as the main objective and construction waste as the results of construction activities. Both are integrated and inseparable in the construction process. In fact, most of the construction managers prefer to manage time, quality, cost and safety to achieve the main product as their concern. Thus, the attention to construction waste is poor. According to the previous research, every construction activity potential for waste generates such as re-designs and modification. Esin, T., and Cosgun, N (2007) stated that most of those activities were (1) material cutting produces 10% of construction waste, (2) modification and demolition produce 92 %; and (3) interior modification contributes 70%. Cochran, K., et al, 2007 estimated that the construction waste derived from the demolition sites is 100% debris and that of construction sites about 10 % of all materials.

In developed countries, many efforts were made to the management of construction waste through the practice of "3R" namely, reuse, recycle and reduce. The construction waste is difficult to be avoided, but it can be minimized. The practice of "3R" activities has become a construction habit and culture in those countries. Construction waste management should be synergic with the construction management. The concern about the construction waste should be equal with and project's objectives. Furthermore, the construction managers should be aware about the existing regulations concerning the waste management. Some Europe countries such as Denmark, Holland and Belgium have been promoting the practice of recycling materials, so that now they have attained about 90% of recycled materials in use. This effort is one of the ways to reduce construction waste (Poon, C. S., 2001). In Hong Kong, it has been promoted the fabrication materials as one of the efforts to minimize construction waste at the construction sites (Jailon, L., et al, 2009). Figure 1.1 describes the construction waste management in developed countries.

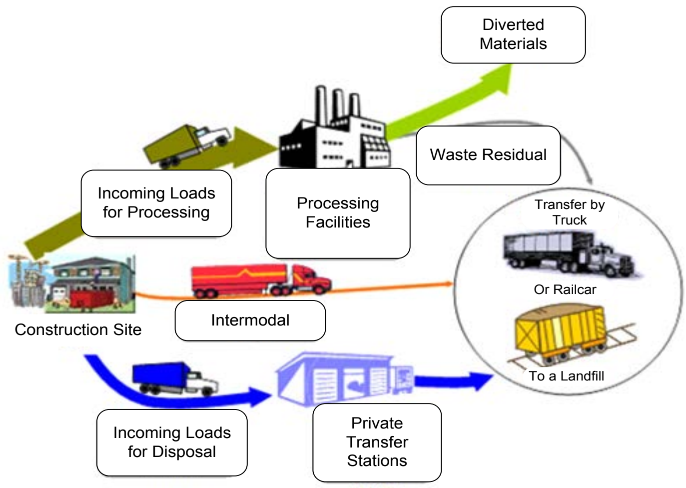


Figure 1.1 Construction Waste Management (Cascadia Consulting Group for King County Solid Waste and Vision, 2008)

In the developing countries, the construction waste will become a serious problem in the future because it contributes a major impact in lowering the quality of environment. Nowadays, they focus on constructing buildings and infrastructures to provide facilities for the economic growth which results in the huge production of construction waste.

The construction atmosphere in the developing countries is different than in the developed countries. The construction system is still in the process of evolving towards the more environmentally friendly construction. To be successful, it should be supported by project participants, government, regulations, and law enforcement to pay attention the management of the construction waste produced during the construction process.

Currently, the construction managers prefer to focus on the profit. Furthermore, they think that the attention to construction waste is always associated to a cost. It means reducing the profit of a project. Therefore, the construction waste is neglected, and most of the construction waste disposal in a private landfill. The government does not provide the specific land fill for construction waste. Commonly, the type of construction waste that disposed is the solid waste such as debris, concrete, brick, and etc. The others construction wastes as steel, wire, and paper, and plastic are re-sold to other people for other purposes. An illustration relates to the construction waste management at a construction site is shown in Figure 1.2. In developed countries, the culture and habit of construction have been stable, in the way that they separate different materials form the construction waste collected.

Figure 1.2 Difference of Waste Management **(**Abarca, L., 2008 and Jones, P., 2004**)**

According to Hore A, V., et al (1997) every 100 housing units are built the amount of construction waste generated equal to construct 10 others housing units. Construction projects are dynamic. A quantity and types of construction waste vary from a project to the others. The amount of construction waste depends on many factors such as the construction type, design, project size, construction method, supervision, and the skill of the worker.

The construction waste is not newest issue in the construction industry. Some researchers have conducted the construction waste research in many countries. They were agreed that the construction waste contributed the large amount of waste production in each country. In Australia, for instance, the construction waste contributes 44% each year (McDonalds, B., and Smithers, M., 1996). In Hong Kong, construction waste contributes 38% each year (Environmental Protection Department, EPD, 2002). In China, construction waste contributes 30% – 40%. The amounts of construction waste productions in some countries are illustrated Table 1.1 below.

Table 1.1 Production of Construction Waste in Each Country (Tam, V.W.Y., 2007)

Country	Proportion of Construction Waste to Total Waste (%)	Country	Proportion of Construction Waste to Total Waste (%)
Australia	44	Japan	36
Brazil	15	Italy	30
Denmark	25-50	Netherlands	26
Finland	14	Norway	30
France	25	Spain	70
Germany	19	United Kingdom	Over 50
Hong Kong	38	USA	29

Li, H., et al (2005) declared that concrete contributed the large amount of construction waste. The productions of concrete in each of the following construction activities are as followins: a construction site that produces concrete waste is 75%; a demolition site contributes 70%; a civil work contributes 40%; and a renovation work contributes 70%. According to Tam, V. W. Y (2007) the major sources of construction waste is as represented in Table 1.2 below.

Table 1.2 Sources of Construction Waste (Tam, V. W. Y., 2007)

Major sources of construction waste	Percentage
Concrete construction	28.9
Steel reinforcement bar	21.1
Formwork	15.8
Temporary hoarding	14.0
Scaffolding	7.9
Material handling	7.0
Finishing	5.3

In the developing countries, the production, control and disposal of the construction waste are managed without good planning. Usually, the quantity of construction waste is known from the number of trucks carrying the waste from the construction site to the landfill. The key of the problem in construction waste management is quantification of construction waste. The research related to the construction waste quantification have been done by Bossink, B. A. G and Brouwer, H. J. H (1996); Guthrie, P. M., et al (1998); Pinto, T., and Agopyan, V (1994); Shi. J., et al, (2006); Cochran, K., et al (2007); Jaime, S. G., et al (2009), and Wang, J. Y., et al (2004).

In Netherland, Bossink, B. A. G., and Brouwer, H. J.H., 1996 were estimated the construction waste approximately 1-10 % of the purchased materials. Guthrie, P. M., et al (1998) declared that the production of construction waste was at least 10 % of all raw materials. In Brazil, Pinto, T., and Agopyan, V (1994) revealed the average of construction waste production approximately 20-30% of the total weight of the materials on the site. The amount of construction waste is difficult to determine. Composition of the construction waste consists of various materials. Majority of wastes are 1) rubbish 40-50% which consists of concrete, bricks, blocks, etc. 2) Wood 20-30% which consists of pallets, forming and framing lumber, treated lumber and shingles. and 3) Miscellaneous 20-30% which consist of plumbing heating, white goods, metals, asbestos tar-based products, painted lumber, plaster glass and other insulation materials, and electrical parts.

Generally, the quantity of waste is estimated from the percentage of the material cost or material purchased. Bossink, B. A. G., and Brouwer, H. J. H (1996), Guthrie, P. M., et al (1998), Pinto, T., and Agopyan, V (1994) are researchers who proposed the method for quantification of construction waste based on the percentage method. Another method according to Shi, J., et al (2006), Cochran, K., et al, (2007), Jaime, S. G., et al (2009) the other researchers who introduced the certain of formula for construction waste estimation is called the formula method. This method is applied for specific materials and certain construction types. There is still another method according to Wang, J. Y., et al (2004) which is called the conversion table method. Quantification was done based on the identical constructions at a previous time. The detail of construction waste method will be discussed in chapter two. The comparison among the three methods is represented in Table 1.3.

Table 1.3 The Previous Method for Construction Waste Quantification

Method to Estimate	Advantage	Disadvantage
Percentage[1]	• Easy to use	• Low accuracy • Difficult to measure (in terms of weight)
The formula[2]	• Easy to use	• Limitations of data • Expensive to update • Require time to use and update it • Low accuracy
The conversion table[3]	• Easy to use	• Limitations of data • Low accuracy • Difficult to create and provide the conversion factors

[1] Bossink, B. A. G and Brouwer, H. J. H (1994); Guthrie, P. M., et al (1994); Pinto, T., and Agopyan, V (1994)
[2] Shi, J., et al (2006) ; Cochran, K., et al (2007) ; Jamie, S. G., et al (2009)
[3] R.S Mean Co. cited in Wang, J. Y., et al (2004)

According to the characteristics of construction projects, they can be distinguished as follows:

- Unique product; the construction products are different one to the others, depending on the owner's objectives.
- Organization and Activities are operated under temporary time. Time is limited, and the organization will be disbanded at the end of a project.
- The product is determined by non-physical conditions such as the regulation, and thus the construction project is different from the others.

Thus, those methods have some disadvantages to be applied in practice. The disadvantages of those methods are a level of accuracy, the limited of a number data and various kinds of waste materials. To apply those methods, one should consider the similar project characteristics, type of waste materials and the updated data. According to the disadvantages, this research would like to purpose an alternative method for construction waste quantification using digital images, where images can be represented the factual condition.

1.2 Problems Statements

In most developing countries, the construction manager cannot answer some questions concerning to the quantification of construction waste. Especially, the waste productions are in daily, weekly, monthly or the total amount of construction waste such as a contribution of the waste to the landfill capacity and contribution to the environment disruption. According to those questions, the researcher defines the research problems based on the existing conditions, and the previous research related to construction waste estimation or quantification as follows:

1.2.1 The existing condition of the construction waste at the construction sites

Currently, the attention to construction waste is not equal compared by the attention to obtain the main objectives of the construction project. Actually, the construction waste is always produced in each construction activity. Most of the construction manager and project participants are thinking that the construction waste is not important and easy to handle. In fact, many construction sites neglect it; the construction managers ignore it, also the habit of project participants throws it without care about the impact of it.

Now, the project participants should be aware of the construction waste, which will be a serious problem in the future. The Kyoto Protocol reminds to all to save of the earth. The construction waste contributes a large amount of the total waste in the world. The construction waste is not only important for the construction manager but also important for an environmentalist. In developing countries, most of the environmentalists have a complaint to the construction project that they only dump of the waste without information of the waste quantity. An environmentalist cannot manage the landfill capacity and determine the environment disruption caused by the construction waste. Thus, the quantity of construction waste is an important issue for the construction managers and the environmentalists.

The quantification of waste is a keyword to the earth saves. In line to it, the quantification of waste is important information to control the environment. The construction manager requires the quantity waste in terms of volume in order to manage a space of the construction site, and the environmentalist requires the quantity waste in terms of weight in order to determine the environment disruption. This research would like to propose an alternative method to construction waste quantification in terms of volume and weight that is easy and practical to use at the construction site.

1.2.2 The Constraints of the Construction Project

According to the fact, the project conditions related to construction waste have some limitations. There are conditions as follows: (1) project duration is in a short period. The construction manager should manage the construction waste during the construction process. Considering project duration, the construction manager should manage the waste generated at construction site, because they need a space for construction activities and store a material properly to improve the productivity of work. The existing of waste at the construction site reduces the accessibility of construction activities and material management during the construction process. (2) All the construction activities are potential to waste generation in various kinds of waste. Also the amount of waste generated is significant. The construction manager requires an alternative method for determine the amount of waste productions in daily or monthly and also total amount of waste generated. Furthermore, the quantity of waste in terms of weight can support the environmentalist to manage the landfill capacity.

1.2.3 Application of the Current Methods of the Waste Quantification

The construction waste is usually disposed without planning. The waste directly loaded to truck without estimating and labeling beforehand. Mostly, the construction managers work on waste quantification using rough estimation and guessing. According to the previous research (the formula, the percentage and conversion table method), all of methods have disadvantages.

The current methods such as the percentage, the formula, and the conversion table method are not practical to apply. Those methods need the data from the previous project. In fact, every construction is unique, different from one to another. Thus, the accuracy of those methods is unsatisfied. Applying those methods to measure construction waste are also time consuming.

1.3 Research Objectives

This research proposes an alternative method for construction waste quantification. It uses digital image to identify weight and volume of construction waste. The sub-objectives of this research as follows:

- To identify the density of construction waste.
- To identify weight and volume of construction waste using digital image via proposed system.

1.4 Research Scopes

The scopes of this research are as follows:

1.4.1 According to the preliminary study and pilot research, this research uses the conical shape as a geometric approach.

1.4.2 Types of construction waste are the structural waste, waste at the different project stage and demolition waste. The construction wastes include bricks, roof tile, concrete mortar, rubble and mixed waste.

1.4.4 To identify the density of construction waste in this research refers to AASHTO T 19 test.

1.5 Research Methodology

The research methodology employed in this study will be as follows.

1.5.1. Preliminary research

(a) Field observation is to identify the habit of workers for waste disposal at the construction site. This step is to identify a shape of the waste stacks.

(b) Review of literature and previous researchers is conducted in order to study the use of a camera to support the image capture at a construction site.

(c) Review of literature and research is conducted in order to study the use of MATLAB for digital image processing and identifying the coordinates for the geometric measurements.

(d) Review of literature and previous research regarding the unit weight test for identifying the density of waste.

1.5.2. Conceptual framework development is introduced based on site practice observation and literature review.

1.5.3. Pilot research is performed to find a geometric approach of the construction waste stack, which is used as a basis for design and development of the proposed system.

1.5.4. System design of the waste quantification system is implemented as follows:

- Development of the procedure for capturing images, which can be a representative of a whole of waste stack.
- Development of the prototype tool for identifying the coordinates of digital images.
- Development of the prototype tool for quantification of waste in terms of volume and weight.

1.5.5. System development and testing are conducted.

1.5.6. Comparing with the other system such as Artificial Neural Networks

1.5.7. Validation of the waste quantification system is performed in the construction projects.

1.5.8. Presentation of the research result, conclusion and recommendation are included.

1.6 Research Contributions

1.6.1 The research outcome will present a new approach to support the construction waste quantification. The outputs will be classified into three main parts as follows:

a) A new approach to quantification of construction waste using digital image.

b) The prototype tool is able to measure waste in terms of volume in cubic meter and weight in kilogram of the construction waste.

1.6.2 Potential benefits of the prototype tool are compared with the percentage, the formula, the conversion table and conventional method are as follows:

a) Easy to use.

   The prototype tool is easy to use. Comparing to the conventional methods, the prototype tool is easier to apply to collect the amount of waste for daily, weekly, or monthly and also total amount of waste generated especially in the multi storey construction.

b) Fast in operation.

   Furthermore, comparison between the prototype and the conventional method such as box/bin, the conventional method requires a number container, labors and it also needs time for collecting and putting the waste into the box.

c) Acceptable in accuracy.

   The prototype tool uses digital image technique and thus the accuracy of a result is under acceptable of normal uses.

1.6.3 The prototype tool provides the economic cost, unlike the expensive technology such as a 3D scanner where the construction industry in developing countries cannot afford.

CHAPTER II
LITERATURE REVIEW

This chapter reviews related research and theories, such as Photogrammetry, MATLAB, and digital image processing. This chapter also presents the previous research in the area of construction wastes and quantification of construction waste.

2.1 Overview of Construction Industry

Construction is a process using a certain method involving resources and equipment, in order to build infrastructure or buildings. Generally, construction consists of some activities integrated into a system called Construction Management. The constraints of construction management are the project objectives, time, quality and cost. The construction manager prefers to focus on the project objectives when compared to the construction waste.

Nowadays, Construction Industry is a dominant sector in each country. It absorbs a finance and man power. The man power employed in construction industry is approximately 10 % yearly, and the growth is twice compared in manufacture industry. The construction industry is the most important factor and a key player in the economic growth in the world. In Indonesia, construction industry is the third important industry besides the food industry and textile. However the construction industry also produces the waste, which contributes to the environment disruption.

2.2 Construction Waste Definition

Construction waste is an unused result from human activities in order to build or assemble building/infrastructure involving resources and using equipment and a certain method to achieve goals. Construction waste consists of residue of materials or non-valuable materials produced directly or incidentally by worker or machines in construction activities (http://www.en.wikipedia.org/wiki/Construction_waste). Waste is a product of industrial activities, which is not economically valuable (Urio, A. F., and Brent, A. C., 2006). Construction waste is defined as solid waste resulting solely from construction activities such as demolition, renovation, and earthworks.

Construction waste is associated to the remaining mud, residues, slurries, and another cast-off generated from construction companies or individuals in the process of constructions, demolition, repairing and renovation. Formosa, C. T., et al (2002) stated the construction waste is close to the debris removed from the construction site and disposed of in a landfill. Construction waste is a result of construction activities as non-valuable things. Figure 2.1 illustrates the construction waste in current practice.

Figure 2.1 Construction Waste in Current Practice

In modern terms, construction waste is classified into two types (1) construction waste related to the production system, and (2) construction waste associated with debris/residue of construction materials. Further discussion, construction waste means solid waste or the construction materials left at the site as unused material/product.

2.3 Construction Waste in Current Practice

In developing countries, the construction industry uses the natural resources as the construction materials such as wood, aggregate, lime and others. Construction industry consumes up to 60% of the natural resources (Cole, J. R., 2000). The main source of construction waste is construction materials. Most of the project cost is allocated to the material purchases. In Africa, the cost of materials absorbs greater than 60%. Most of the cost is allocated on the superstructure part, and the largest part for brickwork is about 25% (http://www.bmtpc.org/cost_of_construction/cost_of_construction_stage_wis.html). A good construction should provide the environmental and economic benefits through taking attention to the impact of construction activities.

Each activity in construction project is potential to waste generate. Construction process contributes the construction waste in various kinds such as noise, pollution, contamination, and etc. Design of construction influences the amount and type of waste. Rounce, G (1998) stated design change, the variability in the number of drawing, and the variability in the level of design details are some factors that potential to waste generation at the design stage. The construction sector generates enormous amounts of waste from the use of natural resources (Poon C, S., 2007). In Brazil, Formoso, C. T., et al (1999) classified the causes of construction waste into six groups as follows:

1. Overproduction; the quantity of work is less than the production for example, mixing mortar at the plastering works.
2. Substitution; the quality of material is out of the standard, the change of design, and etc.
3. Transportation; The transportation problem causes materials defect and broken.
4. Mix processing; the mix processing requires equipment and tools to support the construction material production.
5. Inventories; deterioration of materials occur on the site storage.
6. Defective product; it occurs when the final or intermediate product does not meet the specification or requirements. This matter causes rework and produces waste.

The Hong Kong Polytechnic and Hong Kong Construction Association (1993) conducted research from June 1992 to February 1993 by observing 32 construction sites, and focusing the construction activities that are potential to generate waste, such as reinforced concrete structure, bricklaying, plastering, and ceramic tiling. Those activities generate a large portion of waste caused by the lack of control on material usage by contractors.

Bossink, B. A. G and Brouwers, H. J. H (1996) conducted research in Netherland. They used apartments and residential buildings as research object. Part of their research was to identify the causes of the construction waste generated in each stages of construction process, started from the design stage to the operational stages. The results are shown in Table 2.1.

Table 2.1 Source and Causes of Construction Waste on Each Construction Stage (Bossink, B. A. G., and Brouwers, H. J. H., 1996)

Stages	Causes
Design	• Error in contract documents • Contract documents incomplete at commencement of construction • Change of design • Selection of materials • Choice of low quality product • Lack of attention paid to size of used product • Designer is not familiar with possibilities of different products • Lack of influence of contractors and lack of knowledge about construction
Procurement	• Ordering error, over ordering, under ordering, etc • Lack of possibilities to order small quantities • Use of products that do not fit
Materials Handling	• Damaged during transportation to site/on site • Inappropriate storage leading to damage • Unpacked supply • Throw away packing
Operation	• Error by trade person or labor • Equipment malfunction • Inclement weather • Accident • Damaged caused by subsequent trades • Use of incorrect material, requiring replacement • Method to lay foundation • Required quantity of product unknown due to imperfect planning • Information about types and sizes of product that will be used arrives too late at the contractor
Residual	• Conversion waste from cutting un economical shapes • Cut off from cutting materials to length • Over mixing of materials for wet trades due to lack of knowledge or requirement • Waste from application process • Packaging
Others	• Criminal waste due to damage or theft • Lack of on-site materials control and waste management plans

Also, Chan, Z., et al (2000) declared their research regarding the type of waste and the cause of the occurrence of waste as shown in Table 2.2.

Table 2.2 Classification of Construction Waste and Causes (Chan, Z., et al, 2000)

Type	Causes	Type	Causes
Dust	• Demolition, rock blast • Excavation, rock drilling • Open-air rock power and soil • Open-air site and structure • Bulk material transportation • Bulk material loading and unloading • Open-air material • Transportation equipment • Concrete and mortar making	**Wastes**	• Solid-state waste – building material waste • Solid state waste – building material package • Liquid waste – mud / building material waste • Liquid waste – machinery oil
Harmful Gasses	• Construction machine – pile driver • Construction machine – crane • Construction machine – electric welder • Construction machine – transporting • Equipment • Construction machine – scraper • Organic solvent • Electric welding • Cutting	**Falling Object**	• Solid-state waste – building material waste • Solid-state waste – building material package • Liquid waste – building material waste • Liquid waste – construction water • Construction tools – scaffold & board • Construction tools – model plate • Construction tools – building material • Construction tools – sling / others • Construction tools – scaffold & board • Construction tools – model plate • Construction tools – building material • Construction tools – sling / others
Noise	• Demolition • Construction machine – pile driver • Construction machine – crane • Construction machine – rock drill • Construction machine – mixing machinery • Construction machine – cutting machine • Construction machine – transporting equipment • Construction machine – scraper	**Others**	• Urban transportation – road encroachment • Civic safety – demolition • Civic safety – automobile transportation • Civic safety – tower crane • Civic safety – construction elevator • Civic safety – foundation / earth dam • Urban landscape – structure exposed • Urban landscape – night lighting • Urban landscape – electric-arc light • Urban landscape – mud / waste water • Urban landscape – civic facility destruction
Ground Move	• Demolition • Pile driving • Forced ramming		

Research of construction waste quantification was conducted by some researchers in many countries. According to the research, the construction waste contributes a large amount of waste in each country. They were agreed that the construction industry was a generator of the waste. The researchers give a strong reason that the construction waste will become important issue in the future. Some research showed the amount of waste resulted from construction activities. Enshanssi, A (1996) conducted research in Gaza, Israel. The results of research stated that brick contributes 5.2% of waste. Skoyles (1976) declared that the concrete blocks contribute 7% in one building site. Pinto, T and Agopyan, V (1994) declared that the concrete block contributes 13%, and Soibelman, L., et al (1994) stated that the median contributes 52%. According to Tam, V. W. Y (2008) the major sources of construction waste at a construction site are concrete, which contributes 28.9%, steel bar about 21.1 %, formwork 15.8% and temporary hoarding 14%. In Hong Kong, the construction produced waste up to 21.5 million tons, of which 11% is disposed to the landfill and 89% is disposed to the public filling area. According to the research, concrete is mostly waste generating in each country such as Israel, England, Brazil and Hong Kong. The concrete waste contributes 13 % to 52% of waste.

There was also research related to construction waste generation in other countries. In India, construction industry produces about 14.5 million tons of waste annually, which comprises of sand, gravel, brick, masonry and bitumen. Most of the construction waste is generated from marble cutting, polishing, processing, and grinding to attain up to 6 million tons. Rajasthan produces 95% of the total marble produced in the country, and about 70% of the waste generated from marble processing is disposed locally. Furthermore, the effort to reduce waste through recycling, the old building contributes about 25 % and the new building contributes about 75 %. Most of the research prefers to measure the quantity of waste from construction site perception. On the others hand, that those research have not answer the environmentalist concern related the quantity of waste in terms of weight. A challenge for other researchers is to initiate research to overcome the environmentalist concern.

It is shown by Jailon, L., et al (2009) conducting research in Hong Kong regarding the effect of increasing demand of residential building, which affects the production of construction waste. Moreover, they offered a strategy to minimize the waste production at the construction site. The research suggested to use the recycle and fabrication materials. The recommendation is in line to the current issue related to the Kyoto Protocol, “save of the earth.”

2.4 Construction Waste Classification

Construction project produces a unique product. A project is different from the others in design, construction method, and construction materials. Thus, the construction project also produces waste in various kinds. Many researchers have classified the construction waste into some groups depending on different criteria. Faniran O. O., and Caban G. (1998) classified sources of construction waste into five types, design changes, leftover material scraps, waste from packaging, non reclaimable consumables, and poor design and weather. According to this, the construction waste was classified into two groups as the soft inert waste and the hard inert waste. Soft inert waste types are such as soil, slurry, and etc. Hard inert waste types are rock, debris of concrete and brick, and another inert such as timber, metal, and packing residue. Skoyles, E. R., and Skoyles, J. R. (1987) stated that the construction waste classified based on type of construction activities such as new construction, demolition and excavation.

In housing construction, construction waste is classified into two groups; the structure waste and the finishing waste. Structure waste is the waste such as concrete fragment, reinforcement bars, abandoned timber plate and pieces. Finishing waste is generated during the finishing stage of construction such as over quantity of mortar.

According to Jose, M. C. T. (2005) construction waste is classified into three types; 1) the ordinary construction waste (for example natural stone, sand, mortar, glass, ceramic and etc.) 2) Non-hazardous industrial materials (for example plastic, wreck, wood, cardboard and etc.), 3). Hazardous product or special industrial waste (for example paints, treated wood with heavy-metal oxides, asbestos, and etc).

In developing countries, most of the construction managers pay less attention to the construction waste. In Indonesia, construction waste is not managed properly. Construction waste is classified into two groups called valuable waste and non valuable waste. For valuable waste, they manage properly than non valuable waste. Illustration related to construction waste in Indonesia as shown in Figure 2.2.

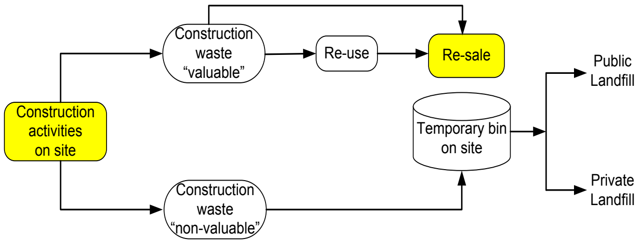


Figure 2.2 Flow of Construction Waste at Construction Site in Indonesia (based on field observation)

Most of the construction waste is disposed to private landfill. The government does not yet provide a specific landfill for construction waste. Currently, the regulations do not control production of waste during construction. Limitation of waste production is important in order to build awareness of the project participants for the construction waste and environment. Information related to the amount of waste and waste production during construction are initial step to manage the construction site for the environment friendly.

2.5 Quantification of Construction Waste

Quantification of construction waste is a crucial issue in waste management. The quantity of waste supports the construction manager to manage the waste properly. Furthermore, the quantity is also important for environmentalist to manage the landfill. In Brazil, the residential building produces 0.095 to 0.145 ton per m^2 of construction and the percentage of 11% -17% of the expected weight of the building.

Acording to Jalali, S. (2006) proposed two approaches for quantification of construction waste, Component Index (CI) and Global Index (GI). Component index (CI) is an approach to estimate the amount of waste based on component of construction. The construction component has a specific function performed by a given expert on the construction site. Furthermore, it is a unit of its own, for example, unit of area or volume. Global index (GI) is an approach providing the information for quantifying of construction waste based on similarity of construction type. The data are usually gathered from previous construction projects.

Moreover, quantification of waste plays an important role in waste management. Key word of waste quantification is waste production. The construction manager can manage the production of waste during the construction process, which is important for environmentalist to manage the landfill. The quantification of construction waste has been conducted in developed countries such as Netherlands, United Kingdom, Brazil, Hong Kong, and etc. According to the research, the methods for waste quantification are classified into three groups; the percentage method, the formula method and the conversion table method. Details of each method are described as follows.

2.5.1 The Percentage Method for Waste Quantification

The percentage method was conducted by some researchers such as Bossink, B. A. G., Brower, H. J. H. (1996), Pinto, T., and Agopyan, V. (1998) as follows.

2.5.1.1. Bossink, B. A. G. and Brouwer, H. J. H. (1996)

The research was conducted in the Netherlands from April 1993 to June 1994 by observing 5 housing projects. The process of research is as follows. Identification the sources of waste during the construction process, as well as sorting and weighing all construction waste materials was conducted. Table 2.3 shows the results of research.

Column 1 shows the result of the material identification. In this case, they identified nine types of materials. Column 2 shows the percentage of waste based on the materials purchased, and column 3 shows costs of waste as the percentage of total waste costs.

Table 2.3 Fraction of Construction Waste (Bossink, B. A. G., and Brouwer, H. J. H., 1996)

Application of Construction Materials	Fractions of Construction Waste (By weight, %)		
	Total Amount of Construction Waste	Purchased Amount of Specific Construction Materials	Costs of waste as percentage of total waste
	(1)	(2)	(3)
Stone tablets	29	9	26
Piles	17	5	13
Concrete	13	3	7
Sand Lime elements	11	1	8
Roof tiles	10	10	13
Mortar	8	10	5
Packing	7	N/A	-
Sand Lime Bricks	3	6	3
Small fraction for metal and wood)	2	-	-

According to table 2.3 column (2), the estimate for the construction waste quantification is about 1-10 % of the purchased materials.

2.5.1.2. Pinto, T., and Agopyan, V. (1994)

Pinto, T., and Agopyan, V. (1994) conducted research in Brazil, and an 18-story residential building project is used as the object of research. The amount of the construction material from supplier and the use of material during construction are used to waste analysis. The research focuses on direct and indirect wastes of 10 building materials. The percentage of waste materials ranged from 1 to 12% in weight, in relation to the amount of materials compared by design. The total waste about 18% of the weight of all materials purchased, equal to an additional cost of 6%.

2.5.2 The Formula Method for Waste Quantification

The formula method was introduced by some researcher such as Formoso, C. T. (2002), Environmental Protection Agent (EPA) (1998), Cochran, K., et al (2007), and Koforola, F.O., et al (2009). Details of the formula method are as follows.

2.5.2.1. Formosa, C. T., et al (2002)

Formosa, C. T., et al (2002) suggested a formula to calculate the construction waste materials. The occurrence of waste was analyzed by considering four different stages of production process;

1. Initial state of materials before delivered to construction site.
2. During transport.
3. During construction activities.
4. After final construction process including due to accidents, theft, vandalism, and other events.

To calculate the quantification of waste, Formosa, C. T., et al (2002) revealed the formula as below wherein the variables of the formula consists of the amount of purchased materials based on the amount of inventories and the quantity of material based on design (Bill of Quantity).

$$\text{aste,} \quad \frac{[\ \text{purchashed}\ ]\ \text{design}}{\text{design}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

Where,

M purchased = the amount of materials effectively purchased by company

Inv = the amount of existing inventories

M design = the amount of materials defined by the measurement of work done

2.5.2.2. Environmental Protection Agent, EPA (1998)

Some researchers adopted the formula from the US Environment Protection Agency, EPA to predict the waste at a new construction. The development of the formula was using statistical data regarding the number, cost and area of construction/demolition. The data are provided by US Census Bureau or from trade organization. The amount of construction waste productions can be calculated using formula 2.2, where the quantity depends on the type of construction activities as demolition, construction and renovation. The EPA provides data related to production waste per each activity in construction.

$$\begin{matrix}\text{Waste produed,}\\ \text{in region}\end{matrix} = \begin{bmatrix}\text{Activity level of construction,}\\ \text{demolition or renovation in region}\end{bmatrix} \times \begin{bmatrix}\text{Waste production}\\ \text{per activity}\end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

2.5.2.3. Cochran, K., et al (2007)

Cochran, K., et al (2007) recommended the estimation of construction waste based on the construction type. A specific activity and different variables of each construction type impact the amount, type, and material size of waste. The construction activities are classified into three groups: new construction, demolition and renovation. Each formula for waste estimation will be explained as follows.

2.5.2.3.1. New Construction

Estimation of construction waste in new construction is represented by Formula 2.3. The amount of waste depends on some variables such as construction cost, unit cost per square meter, production waste per square meter. Furthermore, this formula uses the average cost per area per construction activity based on the project location, called "b" value adopted from table 2.4.

$$\frac{a_c}{b}\sum_{n\;1}^{i}(\;_n\quad _n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where,

C = the amount of construction debris (tons/year)

a_c = the total value of construction activity ($/year)

b = the average cost per area of construction activity ($/m^2)

C_n = the weight of debris per unit area of construction (kg/m^2)

n = the percentage of total construction utility framing type n for any i number of framing types

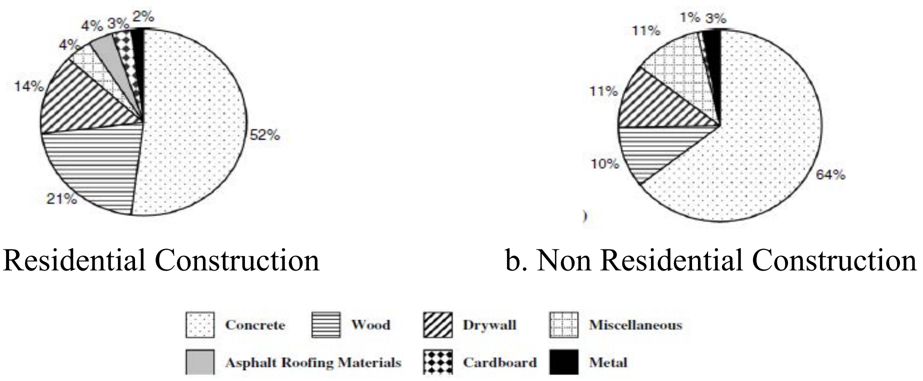


Figure 2.3 Composition of Waste from New Construction (Cochran, K., et al, 2007)

2.5.2.3.2. <u>Demolition</u>

Estimation of construction waste in demolition activity

$$\frac{(a_d \quad)}{g} \sum_{n \quad 1}^{i} (f_n \quad {}_n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.4)$$

Where,

D = the amount of waste generation from demolition (per area)

a_d = the total cost of demolition activity ($)

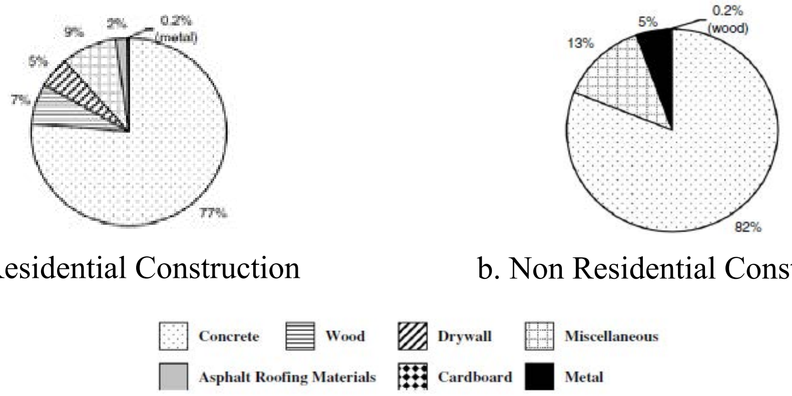
= variable construction type such as residential or non residential

g = an estimate of the cost per unit area of demolition ($/m^2)

f_n = appropriate generation weight per unit area (kg/m^2)

Q_n = various types of home

n, = represents a construction style for i number of style



a. Residential Construction   b. Non Residential Construction

Figure 2.4 Composition of Waste from Demolition (Cochran, K., et al, 2007)

Estimation of construction waste in renovation activity is calculated based on formula 2.5 below. The amount of waste depends on the items of renovation, such as roof renovation.

2.5.2.3.3. Renovation

$$\sum_{n\ 1}^{i} (\ {}_{n}\quad {}_{n}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.5)$$

Where,

M = the amount of waste from renovation

q = the product of the area of renovation (m^2)

C_n = the average waste generation per unit area (kg/m^2), see table 2.4

${}_{n}$ = the percentage of addition that have framing type *n* for any *i* number of framing types

Formula 2.6 below is for calculation of alteration of construction such as repairs of structures

$$(\ s \quad t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.6)$$

N = the amount of construction debris (tons/year)

s = the total value of construction activity (\$/year)

t = the weight of debris per unit area of construction (kg/m^2)

For replacement of roof can be use the formula 2.7

$$v \sum_{n\ 1}^{i} (\ _{n}\quad _{n}) \text{ ....(2.7)}$$

O = the amount of construction debris (tons/year)

v = the total value of construction activity ($/year)

w_n = the weight of debris per unit area of construction (kg/m^2)

ω_n = the weight of debris per unit area of construction (kg/m^2)

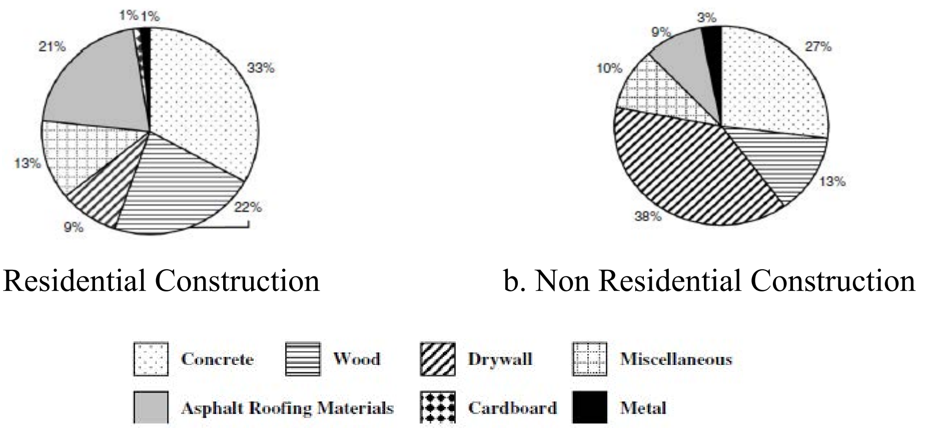
For replacement of driveway can be use the formula 2.8

$$(\ y \quad z) \text{ ....(2.8)}$$

P = the amount of construction debris (tons/year)

y = the total value of construction activity ($/year)

z = the weight of debris per unit area of construction (kg/m^2)



a. Residential Construction

b. Non Residential Construction

Figure 2.5 Composition of Waste from Renovation (Cochran, K., et al, 2007)

Table 2.4 Job-Site Construction, Demolition and Renovation Waste Compositions Determined from Previous Studies, kg/m^2 (Cochran, K., et al, 2007)

Activity	Type	Wood	Dry-wall	Concrete	Brick	Card-board	Asphalt Roofing Materials	Metal	Plastic	Paper	Tile	Misc.	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Residential construction and	Wood frame (a),(b),(c),(d)	12	5.2	0.26	0.51	0.68	0.39	0.30	0.15	0.07	–	1.40	21
residential renovations – additions	concrete frame (e)	6.4	4.9	22.9	–	1.3	1.5	0.90	0.49	–	–	0.93	43.7
Nonresidential construction &	Wood frame (a)	7	0.5	–	–	1	–	–	–	–	–	3	12
nonresidential renovations – additions	Concrete block frame (d)	3.3	5.2	33	–	–	–	1.4	–	–	–	4.7	47
Residential renovations – alterations(f)		29	9.4	25	–	0.99	0.37	0.75	1.3	–	2.3	12	82
Residential renovations –	Asphalt (g)	–	–	–	–	–	12	–	–	–	–	–	12
roof replacements	Metal (h)	–	–	–	–	–	-	6.8	–	–	–	–	6.8
Residential renovations – driveway replacements (kg/job) (i)		–	–	4.1	–	–	–	–	–	–	–	–	4.1
Nonresidential renovations – alterations (a)		4.2	13	–	–	–	–	1.0	–	–	–	2.2	20
Nonresidential renovations –roof replacements	BUR asphalt (j)	–	–	21	–	–	8.0	–	–	–	–	10	40
	SBS-modified bitumen(j)	–	–	–	–	–	–	–	–	–	–	4.1	4.1
	EPDM	–	–	–	–	–	–	–	–	–	–	1.6	1.6
	Asphalt shingle (j)	–	–	–	–	–	12	–	–	–	–	–	12
	APP-modified bitumen (j)	–	–	–	–	–	–	–	–	–	–	3.0	3.0
	Other single plies (j)	–	–	–	–	–	–	–	–	–	–	1.5	1.5
	CSPE (j)	–	–	–	–	–	–	–	–	–	–	1.4	1.4
	PVC (j)	–	–	–	–	–	–	–	–	–	–	2.7	2.7
Residential demolitions	Wood frame multi-family(k)	70	100	300	90	–	20	10	–	–	–	5	595
	Concrete frame single family with concrete slab (i),(l)	–	30	840	–	–	–	–	–	–	–	40	910
	Wood frame single family with crawl space (i)	90	30	–	–	–	15	–	–	–	–	60	195
	Wood frame single family with concrete slab (i),(l)	90	30	240			15					60	435
	Wood frame single family with basement (i),(l)	90	30	530			15					60	725
Nonresidential demolitions Concrete	Framed	1.5	–	690	–	–	–	44	–	–	–	110	845

a McGregor et al. (1993).
b Palermini & Associates (1993).
c NAHB (1995).
d Townsend (1998).
e Cochran (2001).
f ’ Brien & Associates and aler mini & Associates (1993).
g NARC (1996a).
h NARC (1996b).
i Franklin Associates (19
j NARC (1993).
k NAHB (1997).
l Tansel et al. (1994).

A mathematical model for quantification of construction waste from C&D activities has been developed by the NTUA (Fatta, D., et al, 2003). The following equation (2.9) can be used for the calculation of the construction waste.

( ) ……...................………..…………………….(2.9)

Where,

CW = the generated quantities of construction waste (tones);

NC = the surface of new construction (m^2);

OC = the surface of additional or extension construction (m^2);

V = the volume of the generated construction waste per 100 m^2 of surface (m^3 per 100 m^2)

D = the density of generated waste (t/m^3).

The following equation (2.10) is calculation of demolition waste quantity as below.

A F AS …............……………...…………….(2.10)

Where,

DW = the generated quantity of demolition waste (tones);

ND = the number of buildings that were demolished;

ANF = the average number of floors per demolished building;

AS = the average surface of building which is going to be demolished (m^2);

V = the volume of the generated demolition waste per 100 m^2 of surface of demolished building (m^3 per 100 m^2); and

D = the density of generated waste (t/ m^3).

2.5.2.4. Kofoworola, O. F., et al (2009)

Kofoworola, O. F., et al (2009) conducted research in Thailand In order to evaluate the quantity of construction waste and the assumptions are as follows.

(a) new residential building activity generated 21.38 kg/m^2 of waste.

(b) new non-residential building generated 18.99 kg/m^2 of waste.

The conversion factor cited in HQ Air Force Center for Environmental Excellence. The estimated quantity of construction waste by material type for each construction type each year was obtained according to the formula below.

$Q_x = A * G_{av} * P_x = Q_p * P_x$ ....(2.11)

Where,

Q_x = the quantity of construction waste material x tons,

A = the area of construction in m2,

Q_p = the project construction waste generated in tons,

G_{av} = the average waste generation rate

P_x = the average composition of waste material x in %.

To illustrate the formula 2.11, for a new residential building with an area of 1,000 m^2, the amount of construction waste are

= 1,000 m^2 x 21.38 kg/m^2

= 21.38 x 10^3 tons

Table 2.5 shows the amount of construction waste.

Table 2.5 The Amount of Construction Waste, 2002-2005 (Kofoworola, O. F., et al, 2009)

No	**Material**	**10^3 ton**				**Average (%)**
		2002	2003	2004	2005	
1	Asbestos	0.0	0.0	0.0	0.0	0.0
2	Hazardous waste	1.8	2.6	3.2	2.9	0.0
3	Concrete/bricks	354.8	517.2	634.1	586.7	46.0
4	Gypsum	48.4	70.6	86.5	80.1	6
5	Glass	3.6	5.3	6.5	6.0	0.0
6	Insulation/EPS	14.5	21.1	25.9	24.0	2.0
7	Metal	10.2	14.9	18.3	16.9	1.0
8	Paper/Cardboard/Plastic	34.9	50.8	62.3	57.6	5.0
9	Wood	105.9	154.4	189.2	175.1	14.0
10	Unknown composition	200.6	292.4	358.4	331.6	26.0

Referring to Table 2.5 and using the average composition of waste wood of 14%, the estimation of wood waste are as follows.

= 14 % x $21.38*10^3$

$= 2.993 \times 10^3$

The estimations are 3×10^3 tons of wood waste.

2.5.3 The Conversion Table Method for Waste Quantification

Another method for construction waste quantification is the conversion table method cited from R.S. mean data, a company that specializes in publishing construction cost and productivity data. The company provides data to estimate waste, which are the data arranged based on storey of residence and construction components such as wood, plywood, drywall, shingles and carpet. The quantification of construction waste is based on construction material type multiplied by the number of residence storey. Table 2.6 shows the conversion value to calculate quantification of construction.

Table 2.6 Conversion Factors Used in the Estimator Module (Wang, J. Y., et al, 2004)

Materials Construction	1-Storey residence (1600 ft2)	2-Storey residence (2000 ft2)	3-Storey office (20,000 ft2)
Wood (fbm/ft2)	3.21	3.18	0.634
Plywood (ft2/ft2)	3.27	3.01	N/A
Drywall (ft2/ft2)	3.29	5.57	1.52
Shingles (ft2/ft2)	2.49	1.25	N/A
Carpet (ft2/ft2)	0.8	0.8	0.6

Fbm = feet board measurement

Illustration of the waste quantification methods was explained above. The percentage method, the formula method and the conversion table give the advantages and disadvantage for waste quantification. Current problems in quantification of waste are the use of method and level of accuracy. According to literature review, those methods still depend on the data at the previous projects. Thus, the application consumes time. In addition, types of construction materials are dynamic and different from time to time. It influences to the accuracy of the result. With the environment issue, the construction waste contributes to global warming.

The quantity of waste is important to estimate the environment disruption, especially the carbon credit issues. Limitation of waste at the construction site is a way to minimize the environment disruption. Thus, the construction manager should be responsible for the waste production. The construction site needs a tool which is applicable to waste quantification involving the complexity of the construction project such as numerous of construction activities, various kinds of construction materials, variety of labor skill and the multi storey of construction. The important issues are that the tool should support the construction managers and environmentalist need. The capability of the tool should include the quantification of waste production based on daily, weekly or monthly.

2.6 Density of Material

The density of material is influenced by the characteristics of particle such as inter-particle and external particle. External particle, such as type and amount of compact effort, if the amount of effort is higher, thus the material becomes denser.

The internal particles are including the size of material in terms of gradation, shape, surface texture, and strength. Gradation of material contributes to the density value. The uniform gradation has a lower density compared to the mixed gradation. The other factor is material shape such as flaky and elongated, cubical and round. The shape of material influences the volume of void; the large volume of void is an indicator that the density is small. Cubical particles tend to be more densely than flat and elongated particles. Smooth particles are easier to compact than those with rough surface texture (i.e. micro-texture). Aggregates of varying strengths pack differently because one may degrade or break down more than another from the type and amount of compact effort applied. The illustration of both factors that give impact to the density test is shown in Figure 2.6. Figure (a) to (c) show the increase of the density value, which (a) is the smallest and (c) is greatest the density value.

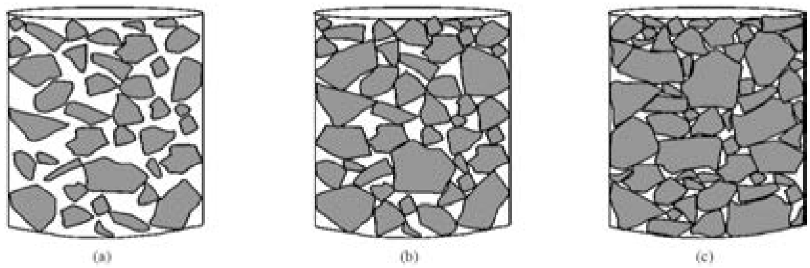


Figure 2.6 The Density Value of Materials Composition

Key word of the density value is minimum void and maximum particles/materials. This condition depends on as those factors above. The density value can be calculated in terms of unit weight of material.

2.7 The Use of Photography for Project Information

Photography in construction is the use of photo for construction purpose such documentations, progress monitoring and progress evaluation. Photography provides the information related to stages of the project. Photography can describe the situation of the construction project.

Foundahl, J. W. (1960) introduced photography for construction project purposes at construction site, and now became a popular method. Construction companies are employing photography for multi proposes. Photography produce data image, which are used as document of the construction activities. Image can illustrate the occurrences at the construction site. The periodically image documentation gives sequence information about construction progress at the actual time.

Currently, Photography is used as a part of routine works in construction project for dispute resolution, accidents investigation, quality insurance, and etc. Wu, F (2009) in this research used photography for construction claim, defect inspection, and recording the building story.

Everett, J. G., Halkali, H., et al (1998) and Ibrahim, Y. M., et al (2008) were used images as data for dispute resolution in construction operation. When disputes arise, the members of project participants use images data as evidence. Photography can record information and provides a useful basis for investigating and solving the cause of problem in construction.

According to the previous research and understanding the capability of photography in the construction project, this research initiates to use photography for monitoring waste production to support the environmentalist related the environmental issues. Scope of works in waste quantification is similar with that research for project documentation or progress monitoring in construction project. The expectation can overcome the problems in waste quantification with the current methods and the conventional methods.

2.7.1 Photogrammetry

Measurement is the activity often occurring in the construction project. The conventional measurement is the physical measurement direct to the object. Currently, the problem of measurement is limited space, where the object is difficult to be accessed. Luhmann, T., et al (2006) presented the method to measure the object without physical contact by using photography. t is called “Photogrammetry.”

Photogrammetry is a practice to determining the geometric attributes of the objects using images/photography. Photogrammetry is combining of technology, science, and art to record the information of the objects including the environment using some processes to find the information as the desired purpose.

Blachut, T. J., and Burkhardt, R. (1989) used image for non-contact measurement based on extracting data from 2D images and mapping them into the 3D image. Photogrammetry for measurement purpose is classified into two types:

1. Metric Photogrammetry - making precise measurements from photos and other image media to determine relative locations of points, distances, scales, angles, areas, volumes, elevations, and the sizes and shapes of objects.
2. Interpretative Photogrammetry - recognizing and identifying objects on aerial imagery and judging their significance.

The automated digital measurement can be classified into two groups as shown in Figure 2.7 below.

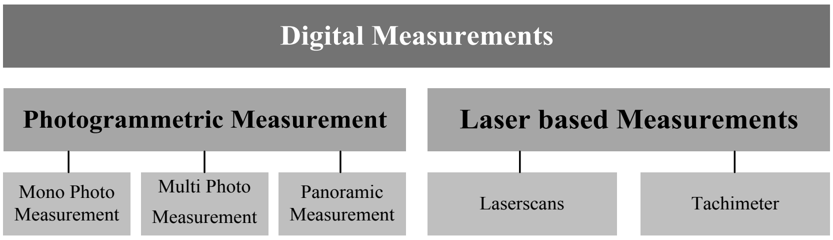


Figure 2.7 The Automated Measurement (Motzko, C., 2006)

Photogrammetry can be used for multi fields and purposes, making thing easier and more efficient. The photogrammetry has been classified into some groups depending on-camera position and object distance, number of measurement images, method of recording and processing, and availability of the measurement results. Details of the classification are shown in Table 2.7.

Table 2.7 Categorization of Photogrammetry (Luhmann, T., et al. 2006)

By camera position and object distance	
• Satellite photogrammetry	• Processing of satellite images, h > *ca.* 200 km
• Aerial photogrammetry	• Processing of aerial photographs, h > *ca.* 300 m
• Terrestrial photogrammetry	• Measurements from a fixed terrestrial location
• Close range photogrammetry	• Imaging distance h < *ca.* 300 m
• Micro photogrammetry	• Microscope imaging, image scale > 1
By availability of measurement results	
• Real-time photogrammetry	• Recording and measurement completed within a specified time period particular to the application
• Off-line photogrammetry	• Sequential, digital image recording, separated in time or location from measurement
• On-line photogrammetry	• Simultaneous, multiple, digital image recording, immediate measurement
By number of measurement images	
• Single img photogrammetry	• Single image processing
• Stereo photogrammetry	• Dual image processing
• Multi-img photogrammetry	• N images where N > 2
By method of recording and processing	
• Plane table photogrammetry	• Graphical evaluation (until ca. 1930)
• Analogue photogrammetry	• Analogue cameras, opto-mechanical measurement systems (until ca. 1980)
• Analytical photogrammetry	• Analogue images, computer-controlled measurement
• Digital photogrammetry	• Digital images, computer-controlled measurement
• Videogrammetry	• Digital image acquisition and measurement
• Panorama photogrammetry	• Panoramic imaging and processing
• Line photogrammetry	• Analytical methods based on straight lines and polynomials

Photogrammetry is also a popular method in construction operation. Jauregui, D., et al, (2003) used photogrammetry for measure the bridge deflection. Photogrammetry requires three modules in application, image acquisition, measurement and interpretation. Interaction of human is needed on each of modules. Knowledge, experience, and skills are required. Figure 2.8 illustrates the sequences of the photogrammetry process.

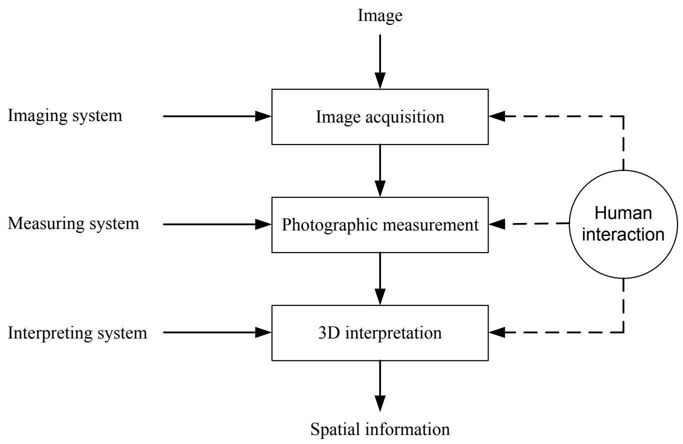


Figure 2.8 Process of Photogrammetric from Image to Spatial (Dai, F., 2009)

2.7.2 Camera and Image Data

Quality of image is influenced by some factors, and classified into two factors, internal and external factor. The internal factor of a camera is setting of camera, which should consider the object and environment. The Internal factor is equal to the camera specifications involving focal length, shutter speed, ISO, aperture, and etc. External factor relates to the environment of object. Outdoor image is more complicate than indoor image. Generally, the camera position in order to image capture is classified into three movements as shown in Figure 2.9 below.

(a) 180^0, landscape position (b) -90^0, counterclockwise portrait (c) 90^0, clockwise portrait

Figure 2.9 Camera Position (Dai, F., 2009)

Transformation form an object to an image plane is equal to the transformation of an object from the world coordinate system to the camera coordinate system. Illustration of transformation can be described as perspective transformation on pinhole camera model in Figure 2.10 below. The coordinate system is denoted by X,Y,Z.

In the world coordinate system, the object represents by 3D system (X,Y,Z) to be transformed into the image coordinates system through the pinhole camera become 2D. Center of the world coordinates system and the camera are represented by the pinhole camera which is utilized to geometric analysis of image. Calculation a point coordinates on image is assumed through the pinhole camera model. Figure 2.10 shows projection the object to the image plane.

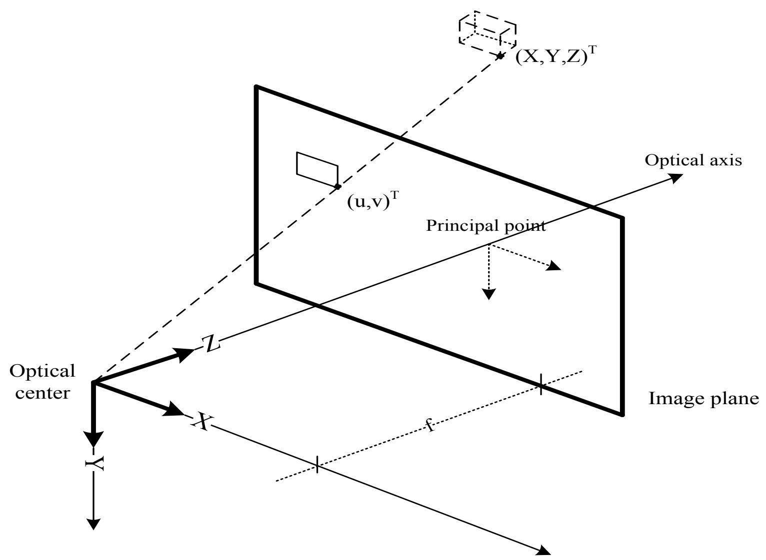


Figure 2.10 Projection of the Object into the Image Plane (Morvan, Y., 2009)

The coordinate of object in image plane (u,v) can be calculated based on the formula below.

$$u = \frac{X*f}{Z} \text{ and } v = \frac{Y*f}{Z} \quad \text{.....} (2.12)$$

Where, f is focal length of the camera. It gives impact to the coordinate value of object. While the camera coordinate system located at the center of image plane, the image coordinate system setup at the top left of plane. Figure 2.11 illustrates comparison between both of the coordinate systems.

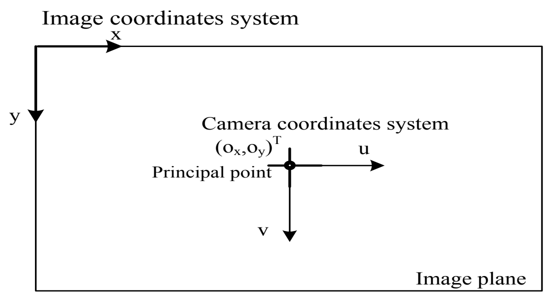


Figure 2.11 Comparison Between Image Coordinate (x,y) and Camera Coordinate (u,v) (Morvan, Y., 2009)

2.8 MATLAB

MATLAB is popular software for engineers. Nowadays, MATLAB is often applied for multi purposes, especially transformation from conventional methods into automation. MATLAB is used as a platform of programming and experiments in this research, which is a high performance in integrating computation, visualization and programming. As well as excellent graphics capabilities, and its own powerful programming language. MATLAB provides toolbox for support a particular task. Also in image processing task, MATLAB provides the image processing toolbox with facilities as follows.

1. Read and write an image data for any formats
2. Provide function for image transformation, filtering, enhancement, feature extraction and others
3. Developable by adding its own function
4. Provide GUIs makes the user easy to operate the program in MATLAB.

2.9 Digital Image Processing

Image processing is transformation from original image to new image using the science of manipulating based on a specific purpose. Image processing is the science of manipulating a picture. Image is represented as matrix, with the size of matrix equal to the size of image. Characteristic of image can be classified into two categories as analog image and digital image. Analog image are images that are still in signal type, while Digital image are captured from the real world of three dimensional objects to a set into two dimensional systems.

A process of changing from digital image to output is shown in Figure 2.12 below. A set of image characteristics begins from object capture in three dimensional become an images in two dimensional then analyzed using the computer based on the certain purpose. An image consists of spatially distinct points and holds a number that denotes the intensity, amplitude, grey level and can be conveniently fed to a digital computer for processing.

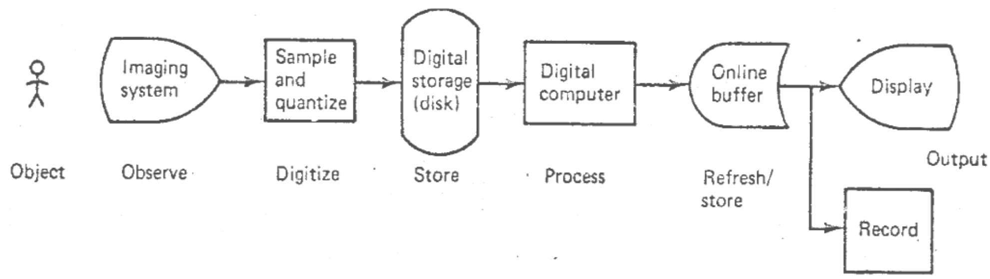


Figure 2.12 Digital Image Processing Sequence (Jain, A. K., 1998)

Image processing can be defined as the function of two variables *f(x,y)*, where *x* and *y* are plane coordinates. The coordinate is represented as pixel, as shown by matrix below.

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-11) \\ \vdots & \vdots & \vdots & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix} \quad \text{.................. (2.18)}$$

In MATLAB, the matrix is represented in below

$$f = \begin{bmatrix} f(1,1) & f(1,2) & \cdots & f(1,N) \\ f(2,1) & f(2,2) & \cdots & f(1,N) \\ \vdots & \vdots & \vdots & \vdots \\ f(M,1) & f(M,2) & \cdots & f(M,N) \end{bmatrix} \quad \text{...................................... (2.19)}$$

According to Sonka, M., et al (2008) the image processing consists of four levels as illustrated in Figure 2.13 below. Starting from determination of objects by considering criteria based on specific purposes. Actually, an image consists of object and background including noise. The enhancement technique is differentiate the objects based on the objective, which the images processes by region, scale, interest point, texture, etc to get the output according to the aim.

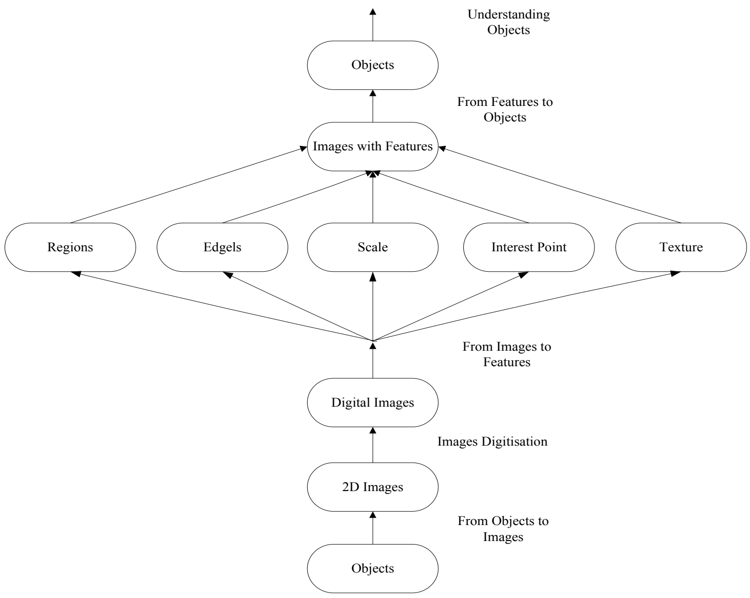


Figure 2.13 The Flow of Image Analysis (Sonka, M., et al, 2008)

Resolution shows quality of image represented by number of pixel. High pixel shows that the image is high quality. Image as data input is often met with some problem such blur, shack, un-homogeneity, un-contrast, and etc. Digital image processing is used to make up image quality. The procedure of image processing follows some steps as illustrated in Figure 2.14 below. The procedures are as follows.

1. Data Acquisition

   Data acquisition is a number of data required the system to obtain the system aims. The characteristic of data follows the system design.

2. Image Pre-processing

   Image pre-processing is a certain process to the data preparation before analysis by the system. This process includes the improvement of its pictorial information such as contrast improvement, elimination of noise and selecting a part of image for observation.

3. Image Segmentation and Edge Detection

   Image segmentation and Edge detection are method for differentiate between object and background. Partitioning of images becomes internal properties or design of external shape characteristics.

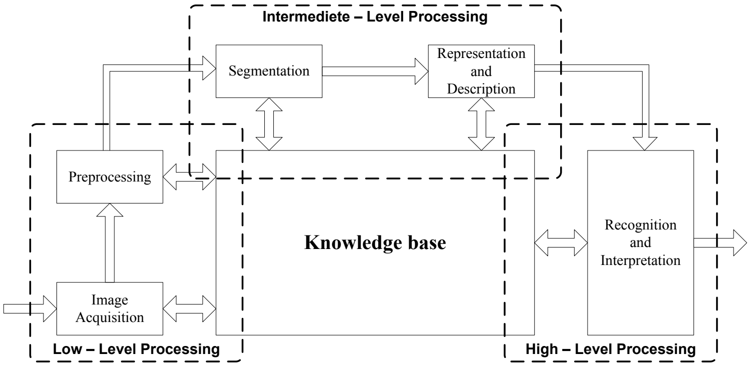


Figure 2.14 Procedures of Image Processing (Gonzales, R. C., and Wood, R. E., 1992)

4. Feature Extraction and Selection

   Commonly, Intensity in-homogeneities often occur in real-world images. Feature extraction is done to measure the amount of quantitative characteristics of each pixel.

The technique of image processing is the process of capturing the real world which is three dimensional to be changed into image of two dimensional. Nowadays, some researchers have conducted some research to maximize image function in cross field, doing analyses based on the image to identify some problem and constraint. The method can be used to analyze image during finding problem solution by transforming the image into three dimensional.

2.9.1 Applications of Digital Image Processing

Implementation of image processing can be applied in various fields. In medical field, digital image processing can be used for chest X-rays, radiology, ultrasonic scanning, nuclear magnetic resonance (NMR), etc. In industrial field, it has been developed to be used for robot vision, cartoon design, fashion design, etc. Actually image processing is to assist human activities. However, this technology has some problems. Jain, A. K. (1998) stated that implementation of image processing has some problems:

1. Image Representation and Modeling

The most important problem is related to fidelity or intelligibility, usually this criterion represented by image quality, which is in relation with the characterization of picture element (pixel). The measurement required model perception of contrast, spatial frequencies, color etc. The criterion to image measurement is illustrated in Figure 2.15 below.

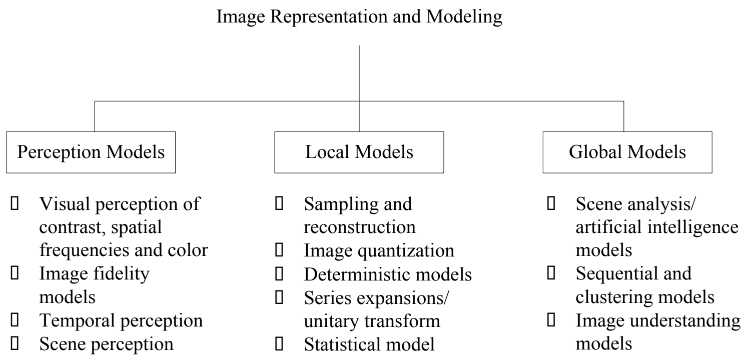


Figure 2.15 Image Representations and Modeling (Jain, A. K., 1998)

2. Image Enhancement

The enhancement processes are done to increase the dynamic range, to sharpen the edges such as boundaries or contrasts to make an image more useful to dispel, detected and easily analyzed. Image enhancement includes grey level and contrast manipulation, noise reduction, edges sharpening, filtering, interpolation and magnification, pseudo coloring, and etc. The technique of image enhancement is shown in Figure 2.16 below.

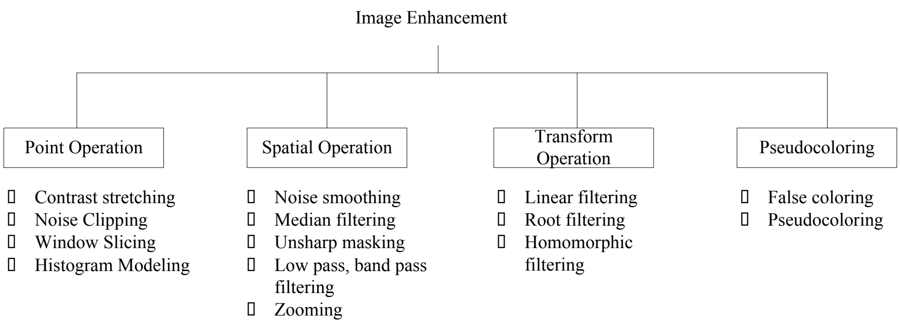


Figure 2.16 Image Enhancements (Jain, A. K., 1998)

3. Image Restoration

Image restoration concerns with filtering the observed image to minimize the effect of degradation. The effectiveness of restoration filters depend on the extent and the accuracy of knowledge the degradation process as well as on the filter criterion. Some techniques can be used in image restoration, illustrated in Figure 2.17 below.

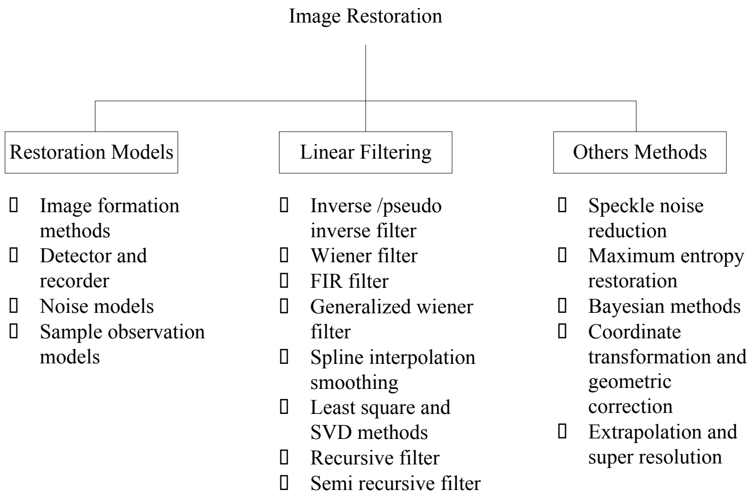


Figure 2.17 Image Restoration (Jain, A. K., 1998)

4. Image Analysis

The image analysis is different from other image operations, the output is another image. Image analysis basically involves the study of feature extraction, segmentation and classification techniques.

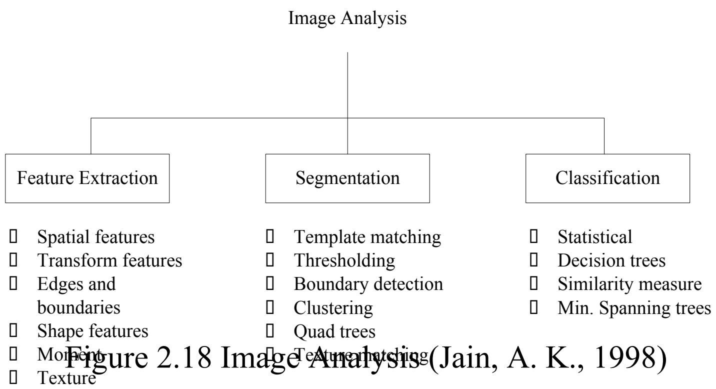


Figure 2.18 Image Analysis (Jain, A. K., 1998)

5. Image Reconstruction

The aim of image reconstruction is to obtain an image of a cross section of the object from these projections. A projection is a shadow gram obtained by illuminating an object by penetrating radiation. Image reconstruction can also be viewed as a special case of image restoration.

6. Image Data Compression

Quality of image is equal with the resolution, which depends on the camera specification. Capacity of transfer media is limited, thus compressing data to minimize of bit. The number of bit respires by pixel unit. Some techniques that can be used in image data compression are illustrated in Figure 2.19 below.

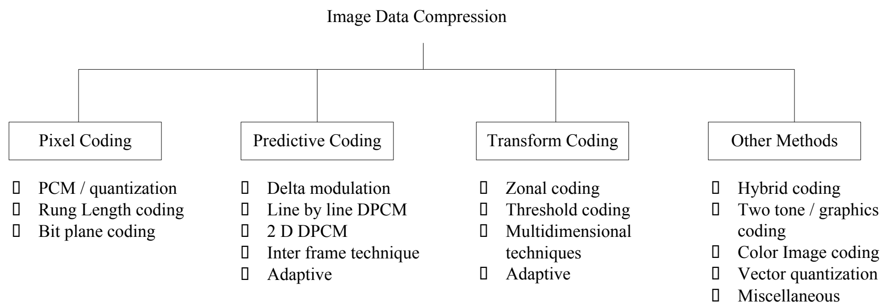


Figure 2.19 Image Data Compression (Jain, A. K., 1998)

2.10 Conclusion

The use of image as data input in a system has some constraints. Digital image processing is required to overcome the limitation of image. The use of outdoor image requires a process to extract the image information to support the system. The problems relate to the environment of an object such as coloring, homogeneity of illumination, contrasting between object and background, and etc.

This research uses the outdoor images as data input. In fact, the construction waste as object and the environment are full color and noisy environment. The digital image processing is required to support the system. Identification object is an important part in the waste quantification system. From literature review and previous research, this research will introduce the digital images for waste quantification in construction project.

CHAPTER III
RESEARCH METHODOLOGY

Chapter 3 describes the research methodology that is applied to reach the research objectives as explained in the first chapter. The research is intended to design and develop a prototype tool for quantification of construction waste using images as data, digital image analysis as technique and the waste density as the important factor to find the quantity in terms of weight. The prototype tool is called "**the Q_{CWI} tool.**"

To support the research, all activities should be integrated, and sequence linked. Research methodology is conducted in nine stages as described in Figure 3.1 below. The research is started from preliminary research and field observation. In this stage, the researcher identifies the information related to the construction project, construction site system and the current situation of construction waste management. Moreover, activities related to habit of workers during a construction process for waste produced and throw of waste. Furthermore, how a construction manager manages the construction waste that involves how the construction waste is quantified, and equally important how the construction manager prepares worker, budget, transportation, and landfill to dispose the waste. The information is used as a basis to create a conceptual framework development.

A conceptual framework is constructed and proposed to overcome quantification of waste at the construction site. In this stage, the initial prototype of the system is designed. A pilot research is used to find the geometric shape of the waste stacks. Moreover, camera setting and a distance to object are tested to support the prototype tool for object capture. Results of the pilot research can be improved by considering the advantages, disadvantages and limitations of it. Thus, the system can be developed better than the initial system.

To ensure the system can be applied for the real problem. Firstly, development of the system should be conducted. Development of the system uses the construction waste model. In this stage, the research finds the information relate to the capability of the system such as the system works and characteristic of the result. Assessment and evaluation are done to improve the system. As the final stage, the quantification system will be implemented to find the capability of the system when applied in real practice. Finally, conclusions and recommendations based on the findings are presented in the last section. The stages of system design and development are described in the next section.

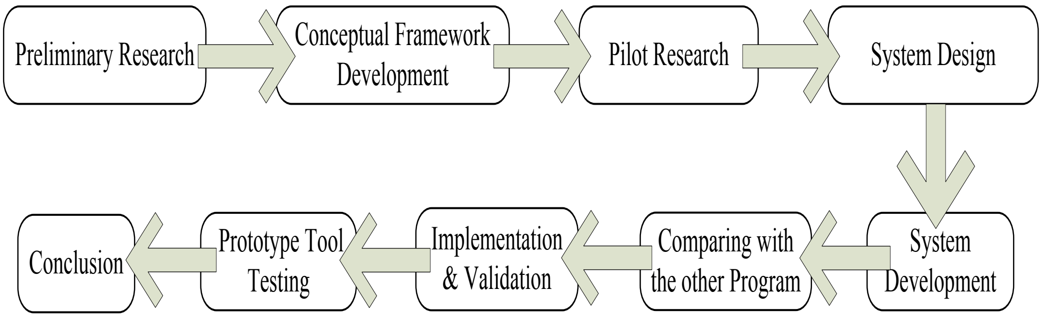


Figure 3.1 Research Methodology

3.1 Preliminary Research

This research is started by reviewing literature related to the topic and conducting field observations to sharpen the problems and ensure that this research has benefits. Exploration on the previous research and the initial studies can be considered as preliminary research for create a conceptual framework.

3.1.1. Field Observation

In this research, field observation and literature review are in unity and complementary to ensure that the research stands on the real problem in the current practice. Problem of construction waste can be identified clearly in this stage. It presents an illustration about the construction waste quantification in current practice. The construction manager activities related to quantification of waste in the site and estimate of budget including transportation and labor, and the decision about the landfill area to dispose the waste during construction.

3.1.2. Literature Review

The literature review is to find out what ways have been done to overcome the quantification of construction waste based on literature and previous research. A solution to waste quantification should cover some criteria, which can represent the factual condition such as easy to use (user friendly), fast in operation, acceptable in accuracy and affordable in cost. Literature review presents (1) an overview on the environment of the construction project by focusing on the current activities by the construction manager related to the construction system, (2) a study on the construction waste characteristics, and classification by focusing on solid waste, characteristic of waste material and density, (3) a study on the principles and mechanism of photography regarding Digital Image Processing (DIP), (4) a study on the use of information technology tools and the programs of MATLAB for system development to provide recommendations on the advantages, disadvantages and limitations of these technologies. Details on literature review are shown in Figure 3.2 below.

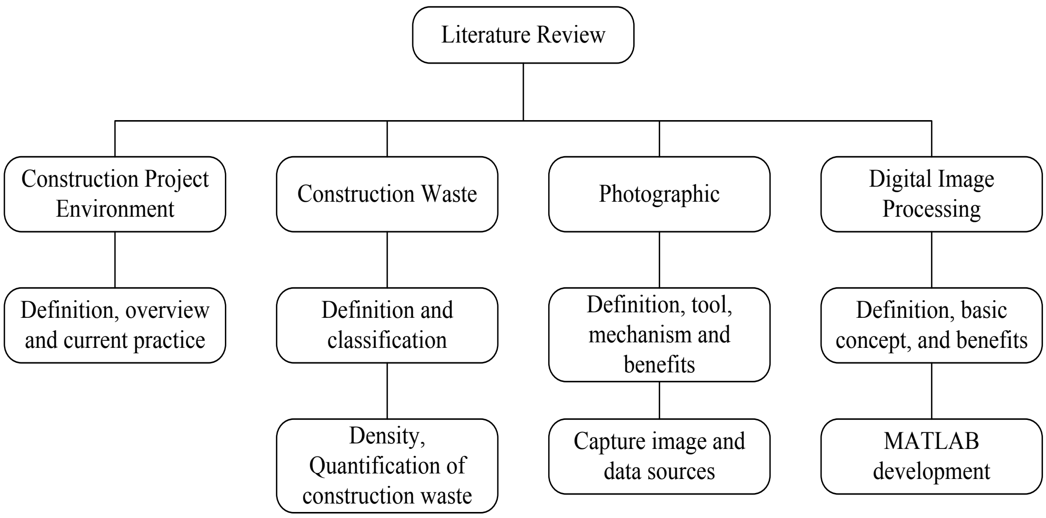


Figure 3.2 Literature Review

3.2 Conceptual Framework Development

The conceptual framework is extracted from field observations and literature review. The system proposes uses image as data source and digital image processing as a technique in waste quantification system. According to literature review images can solve the problems related to newest data and a factual condition. Digital Image Processing as the technique is used to explore images to support the quantification system operation. The conceptual framework presents the possibility of applying this technique to develop the waste quantification system. A flow of methodology and application of digital image processing technique to support each step of the system will be described. Lastly, the expected benefit of using this conceptual framework will be presented at the end of the chapter.

3.3 Pilot Research

A pilot research is an initial stage performed in order to test the conceptual framework of the system. In this stage, the research does a kind of trial-error experiment related to the stack of construction waste and the camera setting and position to image capture in the proposed system. The pilot research is implemented into two steps. 1) trial-error on free fallen material in the way adopts when workers throw the waste at the construction site, 2) trial-error on the camera setting and position in image capture, including angel, focal length, ISO, and etc. The result of this stage is used as guidance to create a conceptual framework and procedures to capture images in this system.

3.4 The Waste Quantification System Design

This section is aimed to presenting the design and development to obtain the proposed conceptual framework. There are several stages in designing and developing a quantification system. The method is used to develop a prototype of quantification system will be explained in three parts: (1) Pre-processing image, (2) identification geometric attribute of the object, and (3) results of the quantification system. This system is built based on MATLAB and EXCEL software. The digital image technique is applied to identify a shape through the geometric attribute coordinates of the construction waste stack. According to the coordinates of shape, the system can measure the geometric measurement (height and width) of the object as basic to calculate quantity of the construction waste. The result of system is integrated into EXCEL and saved in *xls* type.

3.5 The Waste Quantification System Development

In this stage, the construction waste model is used to test the quantification system. The variables of the model are determined beforehand. The model uses an almost of material homogeneous. The system is tested to identify the geometric attributes of the waste model. The result of the system development can be used to improve the system. The density test of waste is done to obtain data for quantification of waste in terms of weight, whereas the test refers to the unit weight of AASHTO T-19 un-compacted test. According to the waste size, the density test is classified into four classes 1) large-size of waste (> 10 cm), 2) medium-size of waste (5-9 cm), 3) small-size of waste (< 5 cm), and 4) mixed size of waste.

The 95 % limit agreement uses to analysis results of the quantification system. This method can illustrate level of confidence of the quantification system. The outline of this section is the methodology of the testing system, type and number of the waste model and the method of evaluation on the result.

3.6 Implementation and Validation of the Q_{CWI} Tool

The implementation and validation are the last stage of research methodology. In this stage, the system is applied on the real construction waste. The construction waste is collected from some construction sites. The truck capacity is used as comparator of the system in terms of volume. Two types of weight are used as comparator. The weight based on the density value, and the weight based on the weighbridge measurement. The result of this stage shows that the accuracy of the quantification system. This section consists of implementation method, case studies, and the validation system. Furthermore, the results of validation are analyzed to identify the limitations and problems concerning the implementation of the system in the real construction. It provides information for further study.

3.7 Conclusion

The findings of this research according to the objectives and the expectation have been mentioned in the first chapter. Meanwhile, the process is done in the same manner as the methodology which has been presented previously. Finally, the results and the recommendations are presented in the last section.

CHAPTER IV
THE CONCEPTUAL FRAMEWORK OF THE WASTE QUANTIFICATION SYSTEM

Chapter 4 describes the conceptual framework as the basis of the Q_{CWI} tool. The system development sets out from the disadvantages of the current methods (the percentage, formula and conversion table method), which have explained at the previous chapter. The conceptual framework offers a method using image/photo as the main data to the waste quantification. The use of a digital camera and the digital image processing are an alternative to overcome the limitation of those methods. The Q_{CWI} tool is built to identify the coordinate points of object to find the geometric attributes of the waste stack. The waste quantification supports the construction managers to quantify the waste as information for environmentalist to manage the capacity landfill. In this chapter, the flow of methodology and the expected benefits of the conceptual framework will be presented.

4.1. Problems of Waste Quantification in Current Practice

The research was conducted in Yogyakarta, Indonesia. Generally, the problems of construction waste in every project are similar. At the construction site, the construction waste disposes in mixed. The construction waste is classified into two groups; non-valuable and valuable waste. This research was focused on the non-valuable waste, especially the solid waste. The advantages and disadvantages of the current methods have been reviewed in chapter two. Commonly, the characteristics and sizes of the construction waste are greatly varied, resulting inaccurate level of measurement. The stack of construction waste was illustrated in Figure 4.1. Volume of the construction waste stack consists of volume of air, water, void and solid waste material.

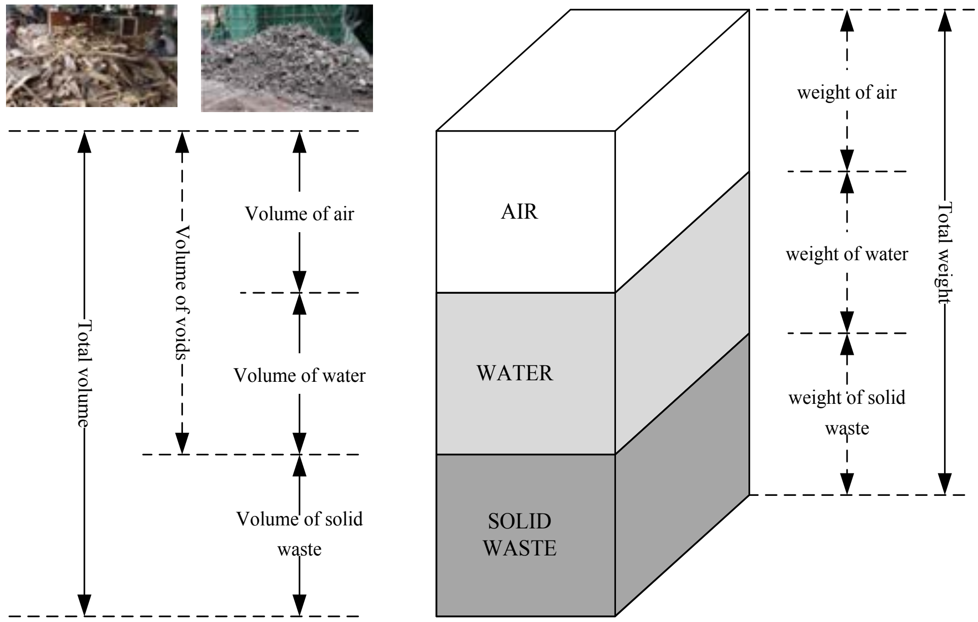


Figure 4.1 Weight and Volume of the Construction Waste Stack

Currently, quantification of waste is done by guessing the amount of waste. In Indonesia and most of the developing countries, the construction managers concern on the valuable waste. They focus on disposing waste from the construction site to the landfill area and they do not pay attention to the environment. On the other hand, environmentalist requires the information related to quantity of waste in order to manage the landfill.

Meanwhile, quantification of construction waste using the meter tape is not accurate because inside the waste stack involving a void. Also the use of tool needs more labor and it is not effective to measure the production waste in the multi storey construction. Therefore, the waste quantification system is proposed as the problem solution.

4.2. The Idea for Overcome the Construction Waste Quantification

After reviewing some relevant literature, this research employs the capability of a camera to produce an image as a source of information and the usefulness of digital image processing technique to overcome the problems of waste quantification. The images provide the information at the actual time and affordable in cost.

Currently, images are also used as data in various fields and its can be interpreted regarding to the certain purpose.

Nowadays, image processing and computer vision techniques are increasingly employed to analyze and interpret an image as a semi-automatic and an automatic approach. They have a direct impact on various applications of an image data. The system is being proposed using digital image processing and two approaches to identify the geometric shape of the waste stack through coordinates of object. The results of this system are designed in EXCEL program and integrated with the density data to calculate the weight of waste. The system is built to ease the use yet accurate in quantifying construction waste.

4.3. The Conceptual Framework for the Waste Quantification System

The above ideas have been explain to the proposal of the conceptual framework of the Q_{CWI} tool at the construction site. The Q_{CWI} tool consists of three modules: they are (1) data acquisition; (2) data transfer; (3) data analysis. Tool of data acquisition consists of a DSLR camera, a tripod and a meter tape. The digital camera is used to the image capture of the construction waste stack while the distance between the camera and the object are measured by using the tape meter. According to photogrammetry, the distance between the camera and the object is classified into the close range. The Q_{CWI} tool requires the object to capture the image in horizontal position. Tripod is used to support the image acquisition. Camera is placed on top of the tripod to get a stable position. Images of the waste stack are captured from three different views, which the image represents the whole of the waste stack. The Q_{CWI} tool calculates the quantity of construction waste based on the geometric attributes (width and height), and the coordinates are used as the references. According to the material waste characteristics and types of the waste stack, the system proposes two types approaches to find the geometric attributes, firstly, the ordinary image and secondly, the smoothed shape. The result of the Q_{CWI} tool is obtained from the average value of both approaches. The proposed quantification system is presented in Figure 4.2.

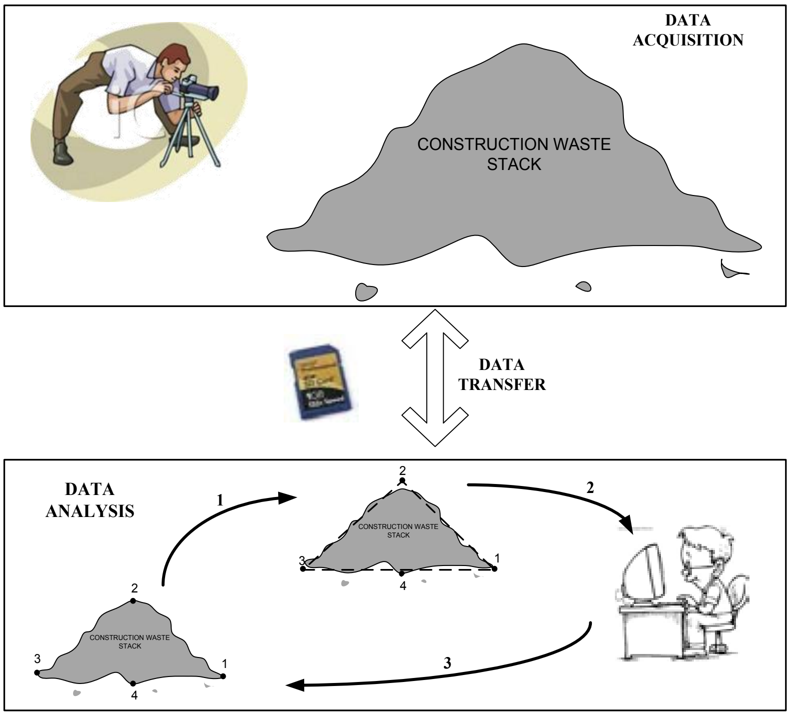


Figure 4.2 The Q_{CWI} Tool Scheme

Module of data transfer consists of the micro disk, a component of the digital camera as data storage. The image data are transferred from the micro disk to a computer/laptop. Then, the analysis of image is carried out and the system is ready to operate.

Module of data analysis consists of pre-processing image, image analysis, and results of analysis. Pre-processing image is a process to reduce unnecessary image captured in a camera such as color, objects, illumination, and etc that commonly happen in an outdoor image, therefore the object can be identified clearly in the image. The enhancement technique of image is a process to help the user to identify the object and differentiate the object and the background of image.

Module of image analysis consists of procedures to quantify the object in image. Image analysis is a process to find the geometric attributes (width and height) of the construction waste stack through coordinates of the point of object. The points selected are the outmost point of object.

4.4. The Q_{CWI} Tool Framework

The Q_{CWI} tool framework consists of four activities (1) image capture, (2) image analysis, (3) density test, and (4) the quantification system. Details of the framework are as follows.

4.4.1. Image Capture

Images data are the important factor to support the system. Quality of image influences the accuracy of the Q_{CWI} tool results. Procedures for image capture are as follows.

4.4.1.1. Tripod and distance

The use of a tripod supports the image capture, especially, if the surface is uneven. Setup of tripod provides maximum support and stability of the camera to avoid image blur or shake. Figure 4.3 shows a setup of tripod. The distance between the camera and the object is fixed at 2.0 m.

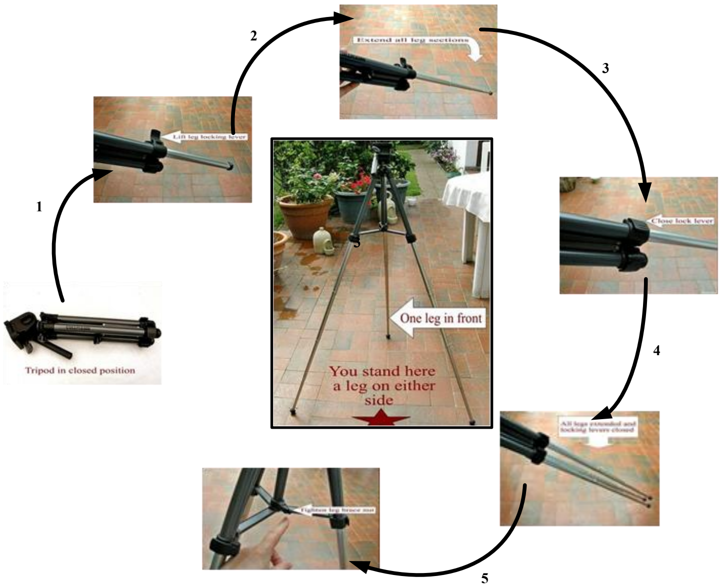


Figure 4.3 Tripod Setup

4.4.1.2. Camera Setup

Generally, a camera has three positions to the image capture; a landscape position to 180^{o}, portrait position -90^{o} (counter clockwise), and portrait position 90^{o} (clockwise). The system requires a camera in the landscape position for image capture as shown in Figure 4.4 below.

Figure 4.4 The Camera 180^0, Landscape Position

4.4.2. Image Analysis

4.4.2.1. Image acquisition and camera calibration

In digital image processing, the coordinate system consists of two types coordinates; they are the object coordinate system and the image coordinate system. Both coordinate systems are right-handed Cartesian. Figure 4.5 shows the mechanism of how the camera forms the image.

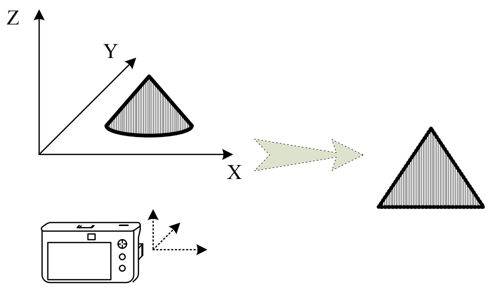


Figure 4.5 Scene of the Camera Position

An illustration of the construction waste stack in cone shape is as shown below.

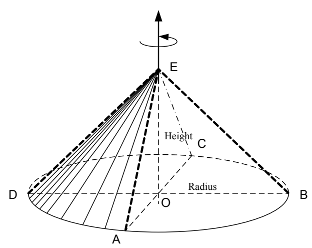


Figure 4.6 Forming of Image at Each Side

According to Figure 4.6 the data input are three images from three different sides. Each image is assumed as a triangle shape, and the image capture is rotated 90^0. The illustration of image from different views is shown in Figure 4.7.

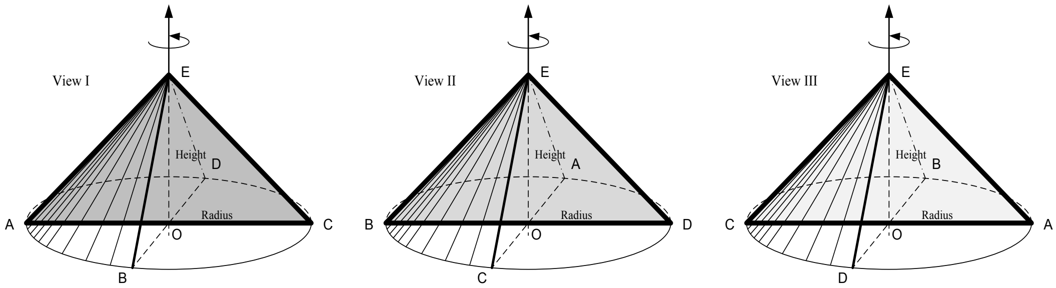


Figure 4.7 Reconstruction of Images

According to Figure 4.7, the quantification analysis for volume and weight of the construction waste stack considers the formulas below.

Average radius of cone $= \frac{AC+BD+CA}{3}$………………………………… (4.1)

Average height of cone $= \frac{OE_I+OE_{II}+OE_{III}}{3}$…………………………… (4.2)

Volume of cone $= \frac{1}{3}$ x π x radius^{2}x height……………………… (4.3)

Weight of cone = volume x density…………………………….. (4.4)

To obtain a good quality of image, one should consider camera condition, camera setup, techniques of image capture and lens specification. According to Dai, F., (2009), the errors of photogrammetry are caused by two factors; human and the lens error. Human error can be avoided by the training and the lens error can be identified by the camera calibration.

Camera calibration determines the internal characteristics of camera (intrinsic parameters), as well as the position and orientation of a camera (extrinsic parameters). Intrinsic calibration is performed by taking one or more images of a calibration target (commonly a chessboard pattern). Extrinsic calibration is performed by finding points common to multiple images and comparing projected pixel locations. This research uses MATLAB Camera Calibration Toolbox for calibration. The camera calibration requires a chessboard pattern as shown in Figure 4.8 below.

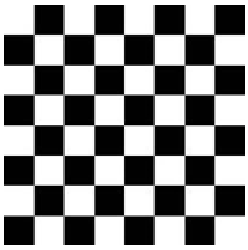


Figure 4.8 Chessboard Pattern

Morrell, H. E. R (2007) stated that the systematic error caused by camera lens distortion and it can be treated by a consistent effect. An image point (x_n,y_n) is transformed into the image plane (x'_n,y'_n) while the coordinates can be calculated by the formula below.

$$x'_n = x_n + dx \qquad (4.5)$$

$$y'_n = y_n + dy \qquad (4.6)$$

dx and *dy* are the camera lens distortion representatively. The results of calibration and the error distribution are shown Figure 4.9 and Figure 4.10 below.

```
Calibration parameters after initialization:

Focal Length:          fc = [ 2005.63325   2005.63325 ]
Principal point:       cc = [ 511.50000   341.00000 ]
Skew:             alpha_c = [ 0.00000 ]   => angle of pixel = 90.00000 degrees
Distortion:            kc = [ 0.00000   0.00000   0.00000   0.00000   0.00000 ]

Main calibration optimization procedure - Number of images: 2
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...Warning: it appears that the principal point cannot be estimated. Sett
14...15...16...17...18...19...20...21...22...23...24...25...26...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 2416.31709   2367.51703 ] ± [ 580.43177   601.80277 ]
Principal point:       cc = [ 531.98130   -67.71047 ] ± [ 0.00000   0.00000 ]
Skew:             alpha_c = [ 0.00000 ] ± [ 0.00000  ]   => angle of pixel axes = 90.00000 ± 0.00000 degrees
Distortion:            kc = [ -0.03359   -5.97205   0.04501   0.00346  0.00000 ] ± [ 0.95969   6.81283   0.15848   0.01757  0.00000 ]
Pixel error:          err = [ 0.05938   0.05531 ]

Note: The numerical errors are approximately three times the standard deviations (for reference).


Recommendation: Some distortion coefficients are found equal to zero (within their uncertainties).
                To reject them from the optimization set est_dist=[0;1;0;0;0] and run Calibration

Pixel error:          err = [ 0.05938   0.05531] (all active images)

done
```

Figure 4.9 The Result of Camera Calibration

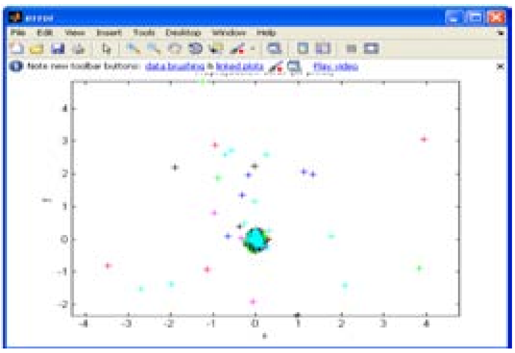


Figure 4.10 The Error Distribution of Camera Lens

The results of the MATLAB Camera Calibration Toolbox are illustrated in Figure 4.11 below.

```
%-- Focal length:
fc = [ 1161.922986825733900 ; 1299.374657071118500 ];

%-- Principal point:
cc = [ 479.475385691744920 ; 687.706528900642070 ];

%-- Skew coefficient:
alpha_c = 0.000000000000000;

%-- Distortion coefficients:
kc = [ 0.100927427066268 ; -0.636409765021402 ; -0.006299150851920 ; -
0.012210285090980 ; 0.000000000000000 ];
%-- Focal length uncertainty:
fc_error = [ 93.736893873809393 ; 158.442819490295160 ];
%-- Principal point uncertainty:
cc_error = [ 0.000000000000000 ; 0.000000000000000 ];

%-- Skew coefficient uncertainty:
alpha_c_error = 0.000000000000000;

%-- Distortion coefficients uncertainty:
kc_error = [ 0.191101911488226 ; 0.524367109211228 ; 0.037923523015374 ;
0.005518659093375 ; 0.000000000000000 ];

%-- Image size:
nx = 1024;
ny = 683;
```

Figure 4.11 Results of the MATLAB Camera Calibration Toolbox

According to Figure 4.9, the results of camera calibration are not found the lens distortion. The distortion coefficients are equal to zero. It shows that the camera is feasible to use for geometric measurements.

4.4.2.2. Image Enhancement

Image enhancement is a technique to improve the quality of image. This technique is a way to assist the user to differentiate the target of object and background of image. It is a part of pre-processing image and can be used if the quality of image is not good. In this quantification system, it is an optional process. Generally, the outdoor images have some problems related to non-homogenous of illumination, contrast, environment color, and etc. Those problems are limitation of the image processing technique. To avoid or minimize the problems, the camera setting should consider the above conditions. The purpose of this step is to improve an object image to be clear and easy to identify. Some software can be used for image enhancement such as Microsoft picture manager, Photoshop, GIMP, ImageJ, and etc.

4.4.2.3. The Identification of Coordinates

The identification of coordinates is part of the data analysis in the quantification system. In this step, the quantification system identifies the coordinates of an object in the image. The coordinate represents the geometric attributes of the waste stacks. To select the coordinates, the users need to consider boundary of the waste stack. This system provides two approaches for coordinate identification. First approach, identification based on the real object on photo/image, it is called “ordinary image.” The points of coordinates are selected based on the outermost of points of the waste stack. Figure 4.12 shows identification of the coordinates based on the ordinary image. Second approach will be explained in next section below.

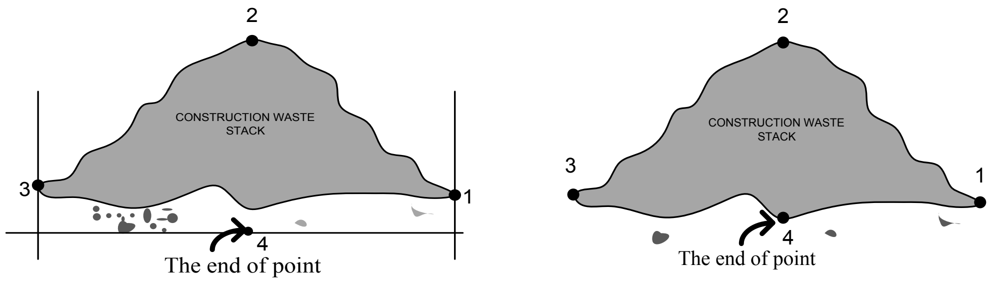


Figure 4.12 Identification of the Waste Stack Coordinates

4.4.2.4. Smoothed Shape

Normally, the shape of construction waste stacks is irregular shape or un-smooth shape. The system of quantification proposes an approach to make up the outline of the waste stack become smooth shape which will help the user find a definite shape and coordinate. This method is called “smoothed shape.” The smoothed shape adopts the quantification method from cut and fills in earthwork, where the cut area is equal to the fill area. Smoothed shape method is shown in Figure 4.13

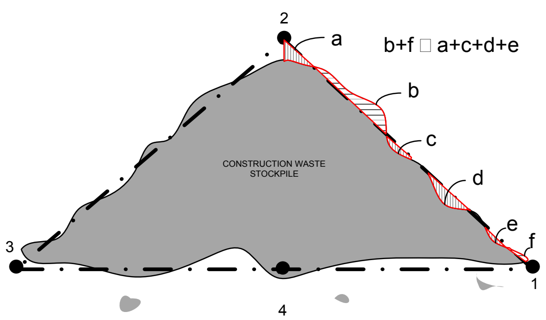


Figure 4.13 The Smoothed Shape

4.4.3. Density Test

According to the literature review, the volume/weight of the waste stack consists of volume/weight of air, water, and solid waste. Volume of the void the waste stack is difficult to measure. The meter tape cannot measure the amount of void. This research proposes to the density value to overcome the void problem in the waste stack. the quantification system uses the density value to find the weight of construction waste.

4.4.3.1. Testing method

Density of materials depends on some factors such as gradation, shape, surface texture, strength, type and amount of compact effort. For example, irregular shape particles tend to be denser than flat and elongated particles. Smooth particles can be compacted easier than the rough surface texture. In this research, the density test is done without compaction.

4.4.3.2. Equipment and Tool

The equipment and tool for the density test consist of mold and shovel. Figure 4.14 shows mold of the density test with radius, height and weight of mold are 56 cm, 38 cm and 7.9 kg respectively.

Figure 4.14 Equipments and Tools of the Density Test

4.4.4. The Waste Quantification System

4.4.4.1. Data transfer

The main data of the system are images. The image is captured by DSLR camera from three views. Image data are saved in micro disk, and transferred to computer through a micro disk port.

4.4.4.2. Data Analysis

Data analysis begins from the coordinate identification. Identification of object employs two approaches as explained in previous section. Dimension of the waste stack can be identified based on coordinates using digital image technique. The coordinates from digital image (in pixel unit) transforms to the metric unit in EXCEL program. The geometric attributes represent width/radius and height of the waste stack.

4.4.4.3. The Q_{CWI} Tool for Construction Waste Quantification

The system employs the MATLAB and EXCEL programs. The script is written under m-file and results are saved in EXCEL. The script program consists of three steps: step-1, Input data or reading data from image, step-2, Identification of the coordinates based on the ordinary image, step-3, identification of the coordinates based on the smoothed shape.

4.5. Expected Benefits of the Q_{CWI} Tool

There are two benefits of the waste quantification system. First, the construction managers can manage the construction waste properly. The Q_{CWI} tool can be used as an alternative tool to quantify the waste. The Q_{CWI} tool offers some advantages in order to construction waste quantification. The advantages are easy to use, fast in operation, and also provide the accuracy of waste quantification. The Q_{CWI} tool uses the factual data, thus not require the data and update from the similar previous project. The Q_{CWI} tool does not require a note to record the information related to waste quantification. The image as data input provides information to calculate the waste quantification. According to the current methods (percentage, formula and conversion table) and the conventional method, the data of construction materials depend on the similar previous project. In fact, the project characteristic is unique and also is dynamic. Thus, the accuracy of the current methods are not good accurate.

Secondly, the Q_{CWI} tool provides advantage for measure the waste production. Actually, a construction project produces the waste during the construction process in various kind of waste. The construction managers need a space to activities and put on materials at the construction site thus they should manage the waste properly. They should dispose the waste to providing the space. On the other hand, environmentalist needs the waste quantity to manage the landfill. According to the above conditions, the Q_{CWI} tool can measure the production waste more easily. The tool does not require more labor and more bins/boxes. The note to record information is also not needed.

4.6. Conclusion

The Q_{CWI} tool framework set out from the current methods as presented in the first chapter. It utilizes photographic image as data, digital image as technique and the density value as important factor to quantification of waste in terms of weight.

According to the Q_{CWI} process, the technique and data analysis can be operated by the construction management staff at site. The Q_{CWI} tool can calculates the quantity of waste quickly. It gives more advantages than the use of the current and the conventional method.

CHAPTER V
DESIGN AND DEVELOPMENT OF THE WASTE QUANTIFICATION SYSTEM

This chapter presents the design and the development of the Q_{CWI} tool to apply the proposed conceptual framework, which is described in chapter 4. Development of the Q_{CWI} tool uses the MATLAB combining with the density value in EXCEL to find the weight of construction waste. The digital image technique identifies the coordinates based on the ordinary image and the smoothed shape to find the geometric attributes of the construction waste stack.

5.1. Design and Development

This section describes the process regarding the development of the Q_{CWI} tool based on the conceptual framework. Some steps for design the Q_{CWI} tool was explained in chapter 3. The concept of this system identifies quantification of construction waste using digital image technique. The result of the pilot research imitates a shape of the waste stack, which is used to determine volume and weight of construction waste.

The implementation of the Q_{CWI} tool is carried out in two steps, the pre-processing image and the Q_{CWI} tool operation. The pre-processing image is required to improve the image quality, which can help the user to disaggregate unwanted object in the image.

The Q_{CWI} tool operation consists of some steps such as image reading, image cropping, grids adding on image, identification the points and the object coordinates. In the smoothed shape, all step are process similarly. The Q_{CWI} tool framework is shown in Figure 5.1 below. The main program of the Q_{CWI} tool is constructed under m-file. Finally, the output of the Q_{CWI} tool can be seen in the Excel which shows the quantification of construction waste in terms of volume and weight of the construction waste.

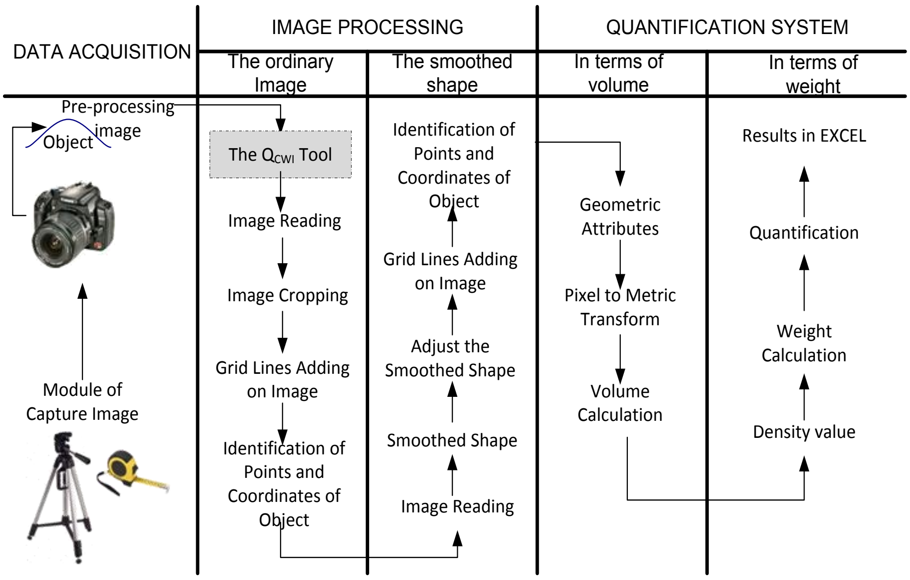


Figure 5.1 Schema of Quantification of Construction Waste System

5.1.1. Pre-Processing of Image

Pre-processing is a part of the quantification system. If the quality of image is not good, pre-processing is required to support the Q_{CWI} tool to identifying the object. This process disaggregates the object from unnecessary background, and the user is easy to identify the coordinates. Figure 5.2 shows differentiation of the image before and after pre-processing image.

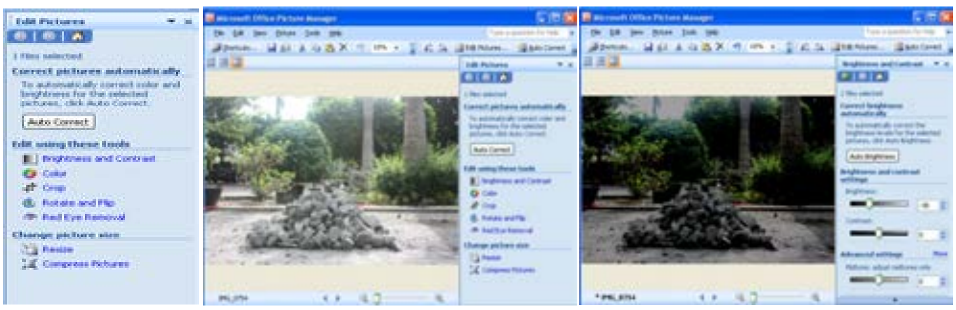


Figure 5.2 Pre-Processing of Image

5.1.2. Data Input

The Q_{CWI} tool requires three images from different views. Views of captured image should represent the whole of the construction waste stack. The image as data inputs is saved under MATLAB directory. This Q_{CWI} tool reads the images sequentially regarding the script commands. The system analysis an image twice based on the ordinary image and the smoothed shape. Codes for image reading are shown in Figure 5.3 below.

```
%%%%%%%%%%%%%%%%%%%Load image%%%%%%%%%%%%%%%%%%
%Identification coordinates based on ordinary image 1
Photo1=imread('filename');
imshow(pathname)

%Identification coordinates based on ordinary image 2
Photo2=imread('filename');
figure, imshow(act1)

%Identification coordinates based on ordinary image 3
Photo3=imread('filename');
figure, imshow(pathname)
```

Figure 5.3 Codes for Image Reading

5.1.3. Image Cropping

Image cropping is a technique to remove unnecessary background to support the users focusing on the object. It also makes the object large and clear. The size of image cropping depends on the object. The process of image cropping is shown in Figure 5.4 below.

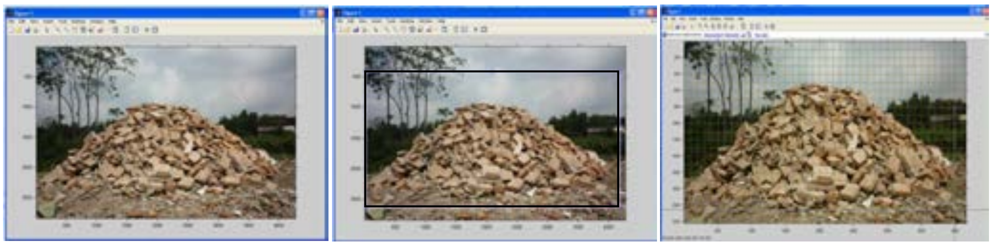


Figure 5.4 Image Cropping Process

Codes for image cropping are as follows.

```
%%%%%%%%%%%%%%%%%%%%cropping image%%%%%%%%%%%%%%%%%
%Identification coordinates based on ordinary image 1
pathname=imcrop("load image");
imshow(pathname)

%Identification coordinates based on ordinary image 2
pathname=imcrop("load image");
imshow(pathname)

%Identification coordinates based on ordinary image 3
pathname=imcrop("load image");
imshow(pathname)
```

Figure 5.5 Codes for Image Cropping

5.1.4. The Grid Lines Adding on Image

This technique guides the users to find the object coordinates by using the grid lines on image. The use of the grid lines can improve the accuracy and precision of the coordinate identification. Figure 5.6 illustrates the image with the grid lines adding. Codes of the grid lines adding are shown in Figure 5.7 below.

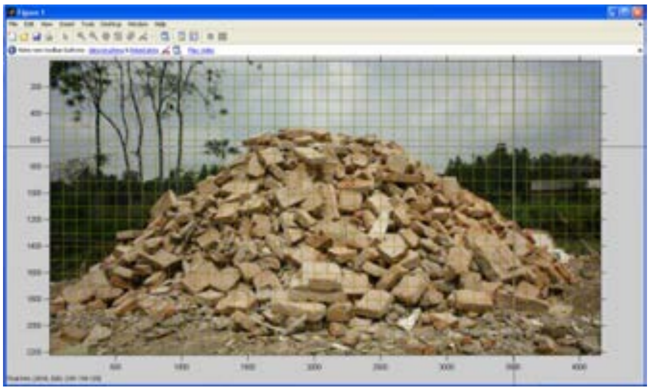


Figure 5.6 Grid Lines on Image

Codes for grid lines adding on image

```
%%%%%%%%%%%%%%%%%%extract grid line on image%%%%%%%%%%%%%%%
hold on
P = size(Photo,1);
Q = size(Photo,2);

for r = 1:scale:A
    x = [1 B];
    y = [r r];
    plot(x,y,'Color','y','LineStyle','-');
    plot(x,y,'Color','k','LineStyle',':');
end
for r = 1:scale:B
    x = [k r];
    y = [1 A];
    plot(x,y,'Color','y','LineStyle','-');
    plot(x,y,'Color','k','LineStyle',':');
end
hold off
```

Figure 5.7 Codes for Adding Grid Lines on Image

5.1.5. Identification of the Object Coordinates

This process is an important step in the quantification system, which is to find the geometric attributes of the waste stack. The quantification system provides two approaches to find the object coordinates based on the ordinary image and the smoothed shape. The coordinates determine based on the outmost points of the object. Codes for identification of the points and coordinate of object are shown in Figure 5.8.

```
%%%%%%%%%%%%%%%%%%Identification of the coordinates%%%%%%%%%%%%%%%%%
axis on;
impixelinfo;
% Get a value from the screen:
[x, y] = ginput(4);
PixelCoordinates1model1=[x, y]
PixelCoordinates2model1=[x, y]
PixelCoordinates3model1=[x, y]
```

Figure 5.8 Codes for Identification of the Object Coordinates

(a) Identification of the Object Coordinates based on the Ordinary Image

Identification of the coordinate uses the ordinary image or the original photo. The height and width of the waste stacks are calculated based on coordinates of the geometric attributes.

(b) Identification of the Object Coordinates based on the Smoothed Shape

According to the waste materials waste characteristics, the stack of construction waste is an irregular shape. The smoothed shape is a technique to make up the waste stack becomes a certain shape, thus the user finds the coordinates of the object easily. Figure 5.9 shows the smoothed shape.

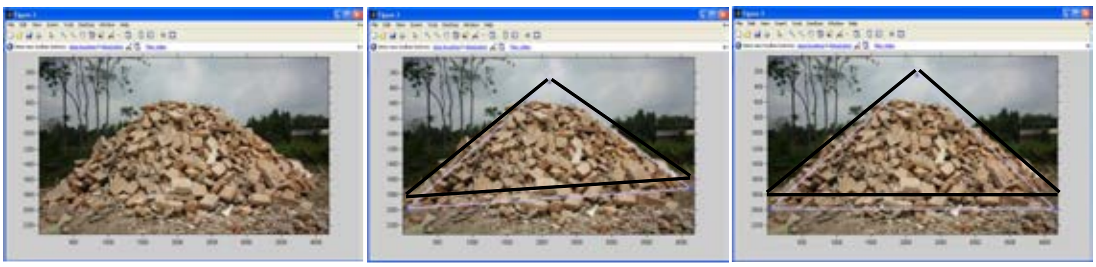


Figure 5.9 Smoothed Shape Approach

5.1.6. Results of the Q_{CWI} Tool

The results of the Q_{CWI} tool are saved in EXCEL file automatically. To avoid misuse of data, the user can compare the results from MATLAB screen and EXCEL file. MATLAB system automatically transfers the coordinates to the EXCEL. The formula is prepared to convert the pixel coordinates system to the metric system. The quantity of the waste is based on the geometric shapes, and the weight of waste is calculated by using the density value. The user can find the results of volume, in cubic meter and weight in kilograms. The system saves the output into a certain file, while sheet and cell are saved in the EXCEL program. Codes for data transfer are shown in Figure 5.10.

```
%%%%%%%%%%%%%%%%%%Transfering data to excel%%%%%%%%%%%%%%%
xlswrite('namefile',[image1],'namesheet','numbercell');
xlswrite('namefile',[image2],'namesheet','numbercell');
xlswrite('namefile',[image3],'namesheet','numbercell');

xlswrite('namefile',[image4],'namesheet','numbercell');
xlswrite('namefile',[image5],'namesheet','numbercell');
xlswrite('namefile',[image6],'namesheet','numbercell');
```

Figure 5.10 Codes for Data Transfer of the Geometric Attributes Coordinates

Figure 5.11 shows the results of the quantification system.

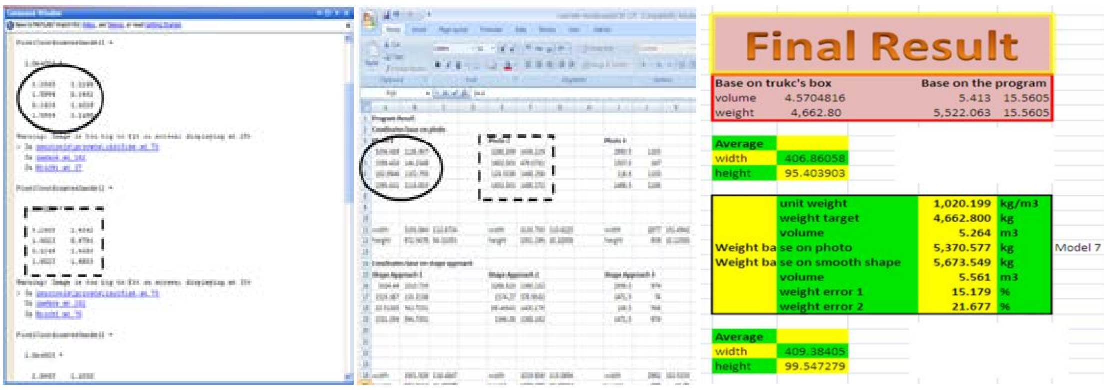


Figure 5.11 Results of the quantification System

5.2. Testing of the Waste Quantification System

The Q_{CWI} tool development is designed to ensure that the system can operate well. Development of the Q_{CWI} tool uses the construction waste models to test and evaluate the reliability of the waste quantification system. The development of the Q_{CWI} tool addresses to quantify the waste in terms of volume and weight. The construction waste models including the attributes of model are designed to facilitate the evaluation of the system.

The materials of waste models are bricks, roof tiles and concrete-mortar. The width/radius of model is designed from 1 m to 1.75 m and the weight is designed from 100 kg to 300 kg. The numbers of models are ten models for each material and material size. The density test of waste materials is done to support the quantification waste in terms of weight. Classifications of waste materials are in line to section

5.2.4. Figure 5.12 shows the flowchart for creating the construction waste model. The model is shown in Table 5.1 below.

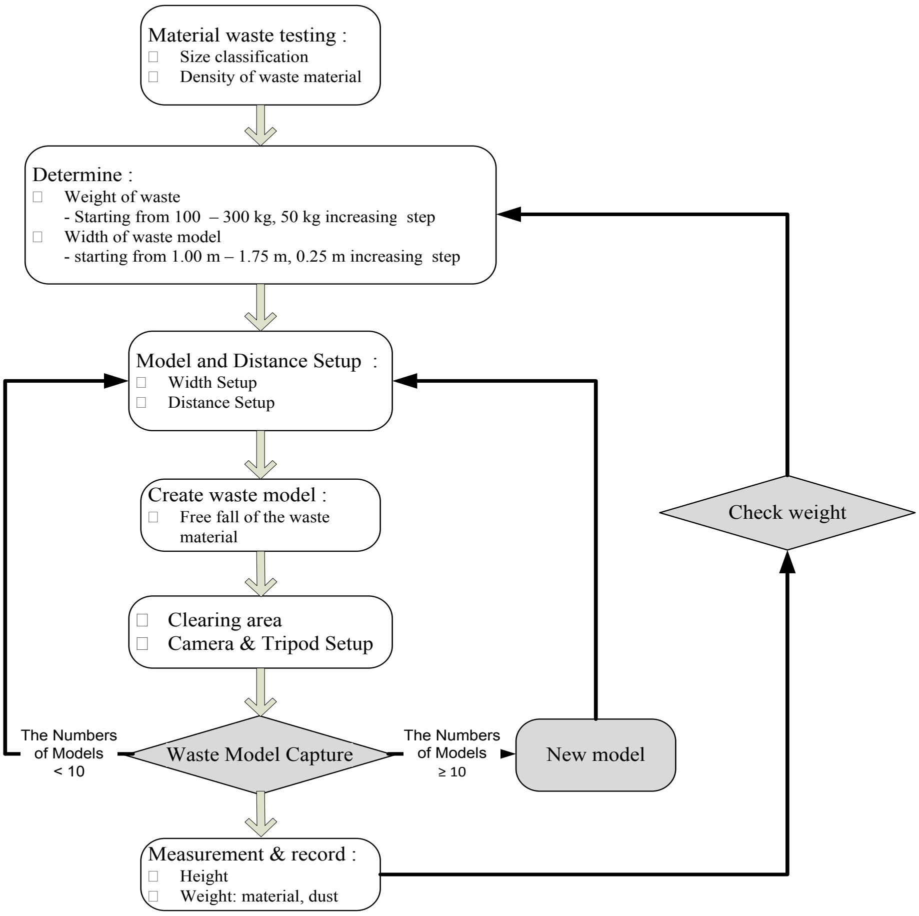


Figure 5.12 A Flowchart to Create a Waste Model

Table 5.1 The Numbers of the Construction Waste Models

Weight (w)/width(L) Variables	The Numbers of Models (unit)		
	Clay Bricks	Clay Roof Tiles	Concrete- Mortar
150/100	10	10	10
150/125	10	10	10
200/125	10	10	10
200/150	10	10	10
250/125	10	10	10
250/150	10	10	10
300/150	10	10	10
300/175	10	10	10
Total Numbers of Models	**80**	**80**	**80**
Total Numbers of Images	**240**	**240**	**240**

Figure 5.13 describes the construction waste models, which are captured from three different views. The shape of waste models is resulted from the pilot research, which is adopted from workers activities when disposing the waste at construction site. The waste models are assumed as the real stack of waste.

Figure 5.13 Illustration of the Construction Waste Model

5.2.1 Construction Waste Model Setup

A model of construction waste begins by setting the base of waste model. The elbow steel was used as a base of model. It was to control width/radius of waste model. The final shape of the waste stack was cone shape. The accuracy was identified from the difference of the construction waste model dimension between the design and measurement using the Q_{CWI} tool. The accuracy was classified into two types in terms of weight and volume. The accuracy can be used as an indicator that the waste quantification system is reliable to quantify the construction waste. The results are used to evaluate and the improvement of the Q_{CWI} tool. Figure 5.14 describes the setup of the base model.

Figure 5.14 Base of the Construction Waste Model

5.2.2 Materials for the Construction Waste Model

The weight of waste follows the design of model as explained in section 5.2. It was prepared in buckets and was weighing by a balance scale as illustrated in Figure 5.15. The weights of the models were always controlled before creating another the waste model.

Figure 5.15 Preparation of the Waste Model Material

5.2.3 The Construction Waste Model

Figure 5.16 describes a process to create the construction waste model. Method and technique adopted workers activities disposing the waste at the construction site. The models were built manually.

Figure 5.16 Create the Construction Waste Model

5.2.4 Density Test

The density of waste material is one of the most important factors in the waste quantification. The density of waste material depends on the size of materials. Sizes of materials were classified into four classes (large, medium, small and mixed size). The density tool test was modified from AASHTO T19 as explained in section 4.4.3.2. The density value was calculated based on the equation 5.1. The volume of mold was equal to the weight of water in mold, 97.53 m^3.

$$\text{Density value} = \frac{\text{weight of material waste(kg)}}{\text{volume of mold}(\text{m}^3)} \quad \text{..................................(5.1)}$$

Numbers of density test were 120 samples. Table 5.2 illustrates the result of the density test. The small size was denser than the others. The concrete-mortar waste model had the highest density value. Details of the density test were included in the appendix of the density test.

Table 5.2 The Results of Density Test (kg/m^3)

Material Type	Density (kg/m^3)			
	Large Size (> 10 cm)	Medium Size (5-9 cm)	Small Size (< 5 cm)	Mixed Size
Clay Bricks	0.764	0.862	0.952	0.911
Clay Roof Tiles	0.587	0.724	0.774	0.717
Concrete - Mortar	1,069	1,126	1,133	1,153

The density value of mixed size materials represented a characteristic of the construction waste materials. Furthermore, it was used to calculate the quantity of waste in the Q_{CWI} tool.

5.3. The Q_{CWI} Testing

The results of the Q_{CWI} tool are the average value from the ordinary image and the smoothed shape. The results were classified into three groups based on the materials types of model (bricks, roof tiles and concrete-mortar). The analysis of each model will be explained in the section below. Detail of the Q_{CWI} tool result was included in the Appendix of the construction waste model.

5.3.1 Bricks Waste Model

In this research, the construction waste model was created in Indonesia. The geometric of waste model was based on design and the dimensions of waste model were controlled by the base, which was checked by using the tape meter measuring (height and width/radius). The width/radius of the model followed the design, and the height followed the maximum height of the materials slump.

Accuracy of waste quantification in terms of weight compared to the weight based on the test design and weight based on the Q_{CWI} Tool. The results of the Q_{CWI} tool were the average results of measuring based on the ordinary image and the smoothed shape. Table 5.3 illustrated the differences of height measuring between the test design of the construction waste model and the Q_{CWI} tool. Details of the comparison to the construction waste model can be seen in the Appendix the construction waste model.

Table 5.3 Comparison of the Height Measuring of the Bricks Waste Model between the Design and the Q_{CWI} Tool

Model Number	Differences of Measuring Based on the Design Vs the Q_{CWI} Tool (in, cm)			The Percentage Error of the Design Vs the Q_{CWI} Tool (in %)		
	Ordinary Image	Smoothed Shape	Average	Ordinary Image	Smoothed Shape	Average
1	-0.749	0.053	0.348	-1.793	0.045	-0.874
2	-1.907	-0.575	-1.241	-4.802	-1.443	-3.123
3	-0.269	0.959	0.345	-0.641	1.962	0.661
4	1.253	3.239	2.246	2.756	7.290	5.023
5	1.306	2.153	1.730	2.663	4.340	3.502
6	2.445	4.684	3.565	4.966	9.227	7.097
7	-2.662	-1.224	-1.943	-5.815	-2.721	-4.268
8	2.571	5.290	3.931	5.202	10.684	7.943

According to Table 5.3, the difference of the height measuring between the model design and the system was in range of 0.345 cm to 3.931 cm, and the average was 1.035 cm. The comparison between the Q_{CWI} tool and design of the waste model was shown by the differences in measuring result. The average of height measuring, the ordinary image was 0.249 cm smaller than the smoothed shape (1.182 cm). The percentage error was in the range of 0.661 % to 7.943 % (the average was 1.995 % ≈ 2%).

The percentage error of the ordinary image was about 0.317% smaller than the smoothed shape which was 3.673%. Figure 5.17 illustrated the differences between the model design and the Q_{CWI} tool measurement.

The waste model number three, 125 cm in width and 200 kg in weight gave a slight difference of 0.345 cm or 0.661 %. The waste model number eight, with the width of 175 cm and the weight of 300 kg gave differences of 3.931 cm or 7.943 %. The waste model number one, two and seven showed that the measuring results were smaller than the design of the waste model.

According to Table 5.4 and Figure 5.17, accuracy of the small size model was better than the large size model, which showed that the difference was not significant. The smoothed shape gave larger differences than the measuring based on the ordinary image.

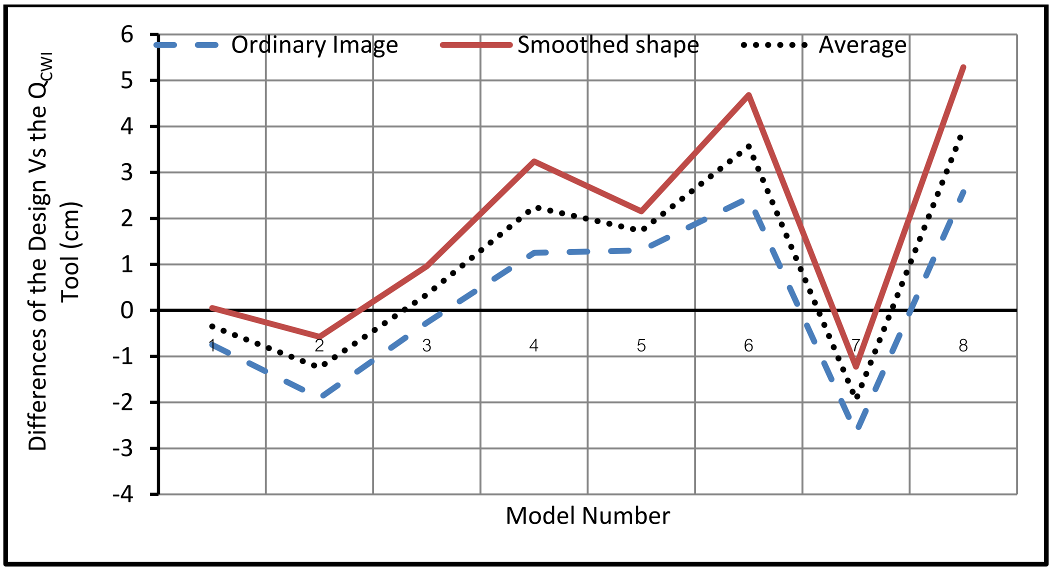


Figure 5.17 Differences of Height Measuring of the Bricks Waste Model Based on the Design and the Q_{CWI} Tool

According to Table 5.4, the maximum difference between the design and the system was 22.549 %, and the minimum error was 0.051%. The average of percentage error was 10.572 %. The percentage error of width measuring was larger than the height measuring.

According to the result, the width measuring tended to provide large error. The other material models show the similar trend. According to the camera specification, especially for the CCD (charge couple device) of the camera, it associates to the size of an object in image. According to camera specification, the ratio of object size in image denoted width and height 3:2. Thus, the error measuring of width was greater than height measuring. Furthermore, the Q_{CWI} tool recommends using the ratio factor to increase the output accuracy.

Table 5.4 Comparison of the Width Measuring of the Bricks Waste Model between the Design and the Q_{CWI} Tool

Model Number	Differences of Measuring Based on the Design Vs the Q_{CWI} Tool (in cm)			The Percentage Error of the Design Vs the Q_{CWI} Tool (in %)		
	Ordinary Image	Smoothed Shape	Average	Ordinary Image	Smoothed Shape	Average
1	2.018	-1.915	0.051	2.018	-1.915	0.051
2	25.700	20.569	23.135	20.560	16.455	18.508
3	12.440	3.112	7.776	9.952	2.490	6.221
4	26.100	15.027	20.564	17.400	10.018	13.709
5	8.624	-4.798	1.913	6.899	-3.838	1.531
6	26.102	14.710	20.406	17.401	9.807	13.604
7	20.436	4.764	12.600	13.624	3.176	8.400
8	42.826	36.094	39.460	24.472	20.625	22.549

Figure 5.18 showed the similar trend with the previous figure, in which the large size model had a larger gap than the small size model.

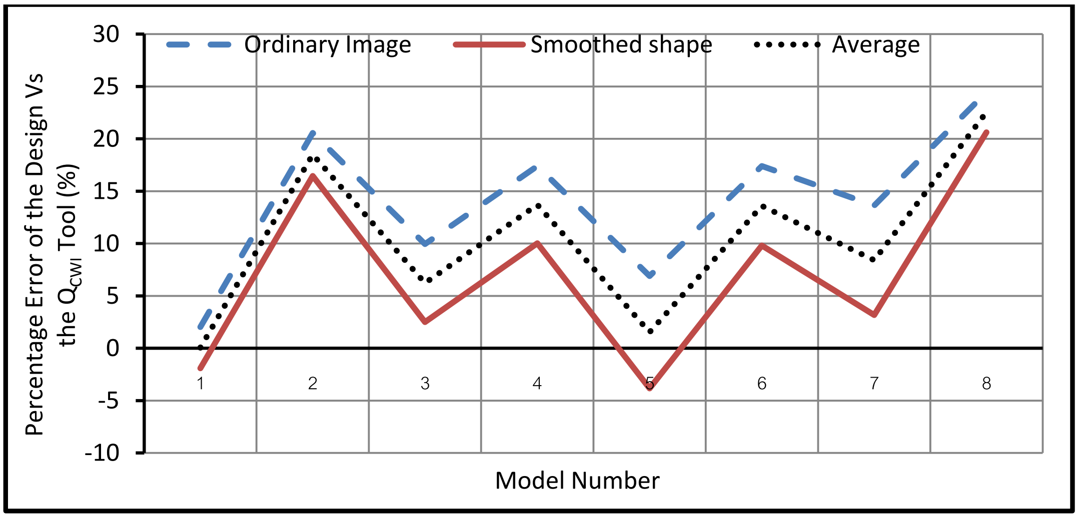


Figure 5.18 Differences of Width Measuring of the Bricks Waste Model Based on the Design and the Q_{CWI} Tool

5.3.2 Roof Tiles Waste Model

The roof tiles materials were different characteristics from the bricks waste model. The characteristics of roof tile materials are flaky and thin. Thus, density of the material was smaller than the others. Furthermore, the model was more unique; the shape of the model was more irregular than other materials as shown in Figure 5.19.

Figure 5.19 The Characteristics of the Roof Tiles Waste Model

According to the roof tiles results, the differences of measuring of the ordinary image were in range of 0.113 cm to 8.289 cm, and the average was 2.399 cm. The results of the smoothed shape were in range of 0.376 cm to 10.037 cm, and the average was 3.570 cm as shown in Table 5.5.

The average of the Q_{CWI} tool was 2.985 cm. It was similar to the bricks model that the smoothed shape had a larger difference than the ordinary image. The average error from both approaches was 5.02 %. For the large size model, number eight had the largest error compared to the model design.

Table 5.5 Comparison of the Height Measuring of the Roof Tile Waste Model between the Design and the Q_{CWI} Tool

Model Number	Differences of Measuring Based on the Design Vs the Q_{CWI} Tool (in cm)			The Percentage Error of the Design Vs the Q_{CWI} Tool (in %)		
	Ordinary Image	Smoothed Shape	Average	Ordinary Image	Smoothed Shape	Average
1	2.321	4.117	3.219	4.66	8.058	6.359
2	-1.283	-0.376	-0.830	-3.249	-1.253	-2.251
3	-0.113	-0.995	-0.554	-0.285	-2.25	-1.268
4	4.242	6.232	5.237	9.293	13.078	11.186
5	-6.358	-2.956	-4.657	-15.963	-7.69	-11.827
6	5.792	5.998	5.895	10.913	11.26	11.087
7	6.304	6.502	6.403	11.536	11.92	11.728
8	8.289	10.037	9.163	13.706	16.579	15.143

The results of the height measuring of the model were shown in Figure 5.20 below. The system showed a similar trend that each model had a similar value. For the height measuring, the maximum error was 15.143% and the minimum error was 1.268%. The results of the waste model number two, three and five were smaller than the design of the construction models.

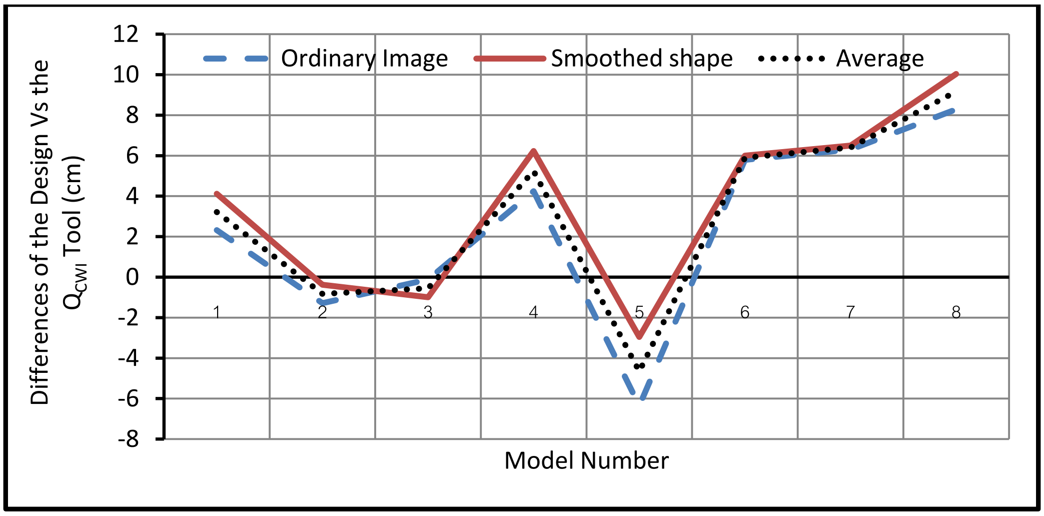


Figure 5.20 Differences of Height Measuring of the Roof Tiles Waste Model Based on the Design and the Q_{CWI} Tool

For the width measuring the percentage error of model number eight was 23.369 %, which was the maximum of percentage error. The minimum error was shown in the model number five 0.084 %.

Table 5.6 Comparison of the Width Measuring of the Roof Tiles Waste Model between the Design and the Q_{CWI} Tool

Model Number	Differences of Measuring based on the Design Vs the Q_{CWI} Tool (in cm)			The Percentage Error of the Design Vs the Q_{CWI} Tool (in %)		
	Ordinary Image	Smoothed Shape	Average	Ordinary Image	Smoothed Shape	Average
1	2.018	-1.915	0.051	-3.881	-17.45	-10.666
2	25.7	20.569	23.135	9.382	4.221	6.802
3	12.44	3.112	7.776	7.213	1.175	4.194
4	26.1	15.027	20.564	22.169	18.991	20.580
5	8.624	-4.798	1.913	6.798	-6.966	-0.084
6	26.102	14.71	20.406	17.474	14.058	15.766
7	20.436	4.764	12.600	15.762	10.736	13.249
8	42.826	36.094	39.460	24.617	22.12	23.369

The similarity between the brick waste model and roof tiles waste model where the biggest size model (width=175 cm, weight 300 kg) was found a maximum error. The model number five was smaller than the other designs.

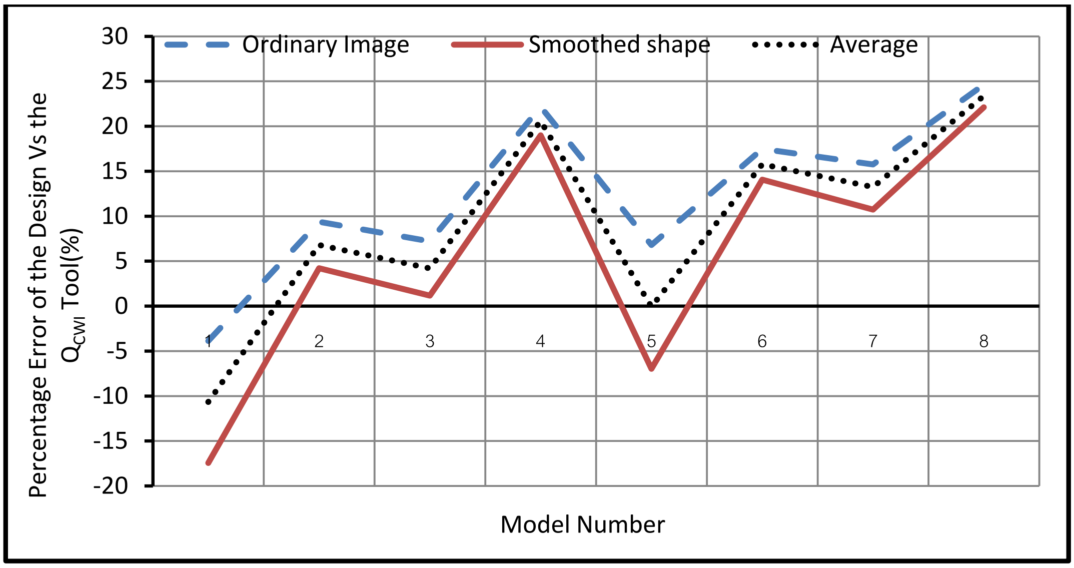


Figure 5.21 Differences of Width Measuring of the Roof Tile Waste Model Based on the Design and the Q_{CWI} Tool

5.3.3 Concrete Mortar Waste Model

The concrete-mortar waste models were different characteristics compared to the bricks and the roof tiles model. Debris of the concrete-mortar is round shape. The maximum difference of height measuring was about 7.006 cm and the minimum was 0.895 cm. Details of the measuring result was shown in Table 5.7 below.

Table 5.7 Comparison of the Height Measuring of the Concrete-Mortar Waste Model between the Design and the Q_{CWI} Tool

Model Number	Differences of Measuring Based on Design Vs the Q_{CWI} Tool (in cm)			The Percentage Error of the Design Vs the Q_{CWI} Tool (in %)		
	Ordinary Image	Smoothed Shape	Average	Ordinary Image	Smoothed Shape	Average
1	-2.37	-2.365	-2.368	-7.165	-7.027	-7.096
2	-5.63	-2.12	-3.875	-16.034	-6.079	-11.057
3	-4.563	-0.927	-2.745	-11.386	-2.323	-6.855
4	-0.195	2.629	1.217	-0.786	-5.994	-3.390
5	-4.837	-5.839	-5.338	-10.635	-12.834	-11.735
6	6.911	7.1	7.006	2.365	3.591	2.978
7	-2.662	-1.224	-1.943	-5.815	-2.721	-4.268
8	-1.01	2.8	0.895	-2.2	5.82	1.810

The percentage error was in range of 1.81 % to 11.735 %. The biggest error was shown in model number five. According to Table 5.7, the maximum difference was found on the model number six. This result was different from the other waste materials.

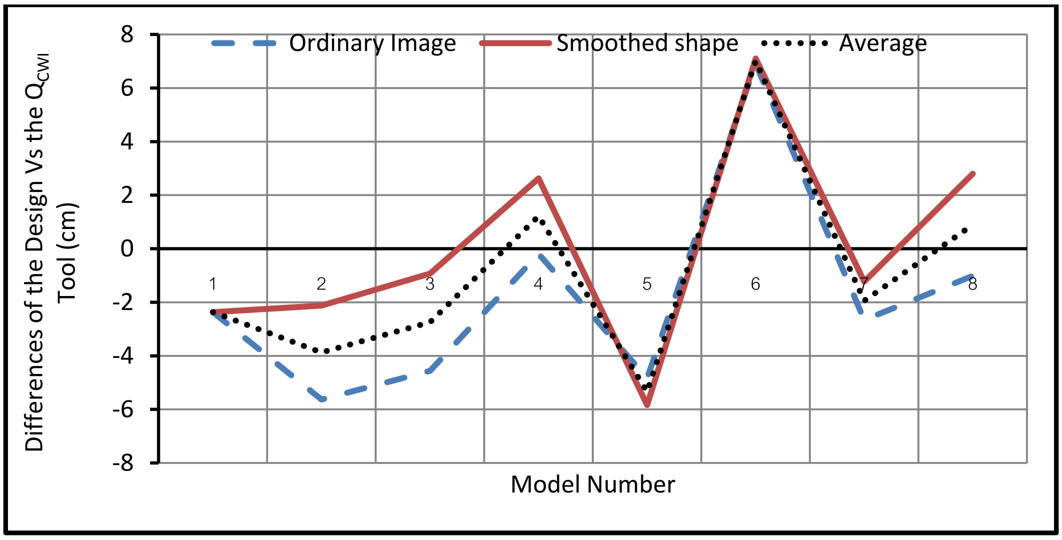


Figure 5.22 Differences of Height Measuring of the Concrete Mortar Waste Model Based on the Design and the Q_{CWI} Tool

The difference of width measuring was larger than that of the height of model. The maximum error was 18.67 % and the minimum error was 0.999 %. Figure 5.23 shows details of the measuring results.

Table 5.8 Comparison of the Width Measuring of the Concrete Mortar Waste Model between the Design and the Q_{CWI} Tool

Model Number	Differences of Measuring Based on the Design Vs the Q_{CWI} Tool (in cm)			The Percentage Error of the Design Vs the Q_{CWI} Tool (in %)		
	Ordinary Image	Smoothed Shape	Average	Ordinary Image	Smoothed Shape	Average
1	4.692	-2.694	0.999	4.692	-2.694	0.999
2	12.467	6.963	9.715	-9.973	5.57	-2.202
3	3.313	1.07	2.192	2.65	0.856	1.753
4	29.486	17.715	23.601	19.657	11.81	15.734
5	-6.928	10.48	1.776	-5.542	-8.384	-6.963
6	7.984	9.151	8.568	3.08	7.329	5.205
7	20.436	4.764	12.600	13.624	3.176	8.400
8	37.49	27.85	32.670	21.42	15.92	18.670

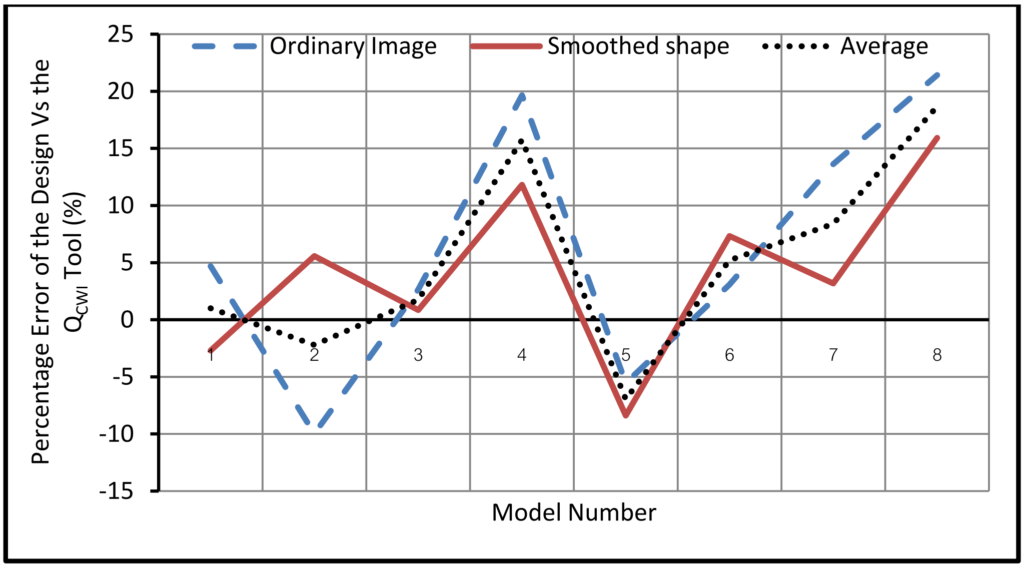


Figure 5.23 Differences of Width Measuring of the Concrete-Mortar Waste Model Based on the Design and the QCWI Tool

5.4. Analysis of the Q_{CWI} Tool Results

The Q_{CWI} tool analysis was done by comparing the result of Q_{CWI} tool and the model design. The analysis was classified into two groups based on the volume and the weight of the construction waste. The volume of construction waste was determined based on the conical shape formula.

5.4.1 Volume of the Construction Waste Model

The attribute of conical shape was identified from the coordinates, in pixel unit and transformed to the metric unit. The Q_{CWI} tool assumed that each object in an image as a triangular shape. Thus, the width/radius and height of the cone were the average value from the three images as data input.

Table 5.9 shows the comparison of volume of the bricks model based on design and the Q_{CWI} tool. The results of the small size model (model number one to five) showed similar in value. The difference of the volume between the design and the Q_{CWI} tool was about 0.04 m^3. The difference of volume of the ordinary image (0.103 m^3) was larger than the smoothed shape (0.078 m^3).

Table 5.9 Comparison of Volume Measuring of the Bricks Waste Model between the Design and the Q_{CWI} Tool

No	Measuring of the Waste Model Using the Tape Meter			Measuring of the Waste Model Based on the Q_{CWI} Tool					
				Ordinary Image			Smoothed Shape		
	Width (cm)	Height (cm)	Volume (m^3)	Width (cm)	Height (cm)	Volume (m^3)	Width (cm)	Height (cm)	Volume (m^3)
1	100	42.48	0.14	97.52	43.59	0.14	101.92	42.79	0.15
2	125	40.92	0.21	98.16	42.83	0.14	104.43	41.50	0.15
3	125	44.85	0.23	111.23	45.12	0.19	121.89	43.89	0.22
4	150	42.84	0.32	129.01	41.59	0.23	134.97	39.60	0.24
5	125	46.92	0.24	115.28	45.61	0.20	129.80	44.77	0.25
6	150	48.64	0.36	124.41	46.20	0.24	135.29	43.96	0.27
7	150	49.00	0.37	129.28	47.80	0.27	140.09	46.70	0.31
8	175	49.49	0.51	131.87	46.92	0.27	138.91	44.20	0.28

Figure 5.24 illustrated the differences of volume based on the design and the Q_{CWI} tool. The results indicated that the large size model showed a larger gap than the design. The analysis used the regression, which can evaluate the agreement between two types of results of measuring on the same models. The regression method consists of a slope value, an intercept value and the determination coefficient. Each of value will be representing linear relationship; especially, the determination coefficient (r^2). According to r^2, we can find the correlation coefficient which is denoted by “r”. It shows the strength of linear relationship between two type measurements. The “r” value can be used to measure the relationship between two type of measurements. It also represents a measure on how well the correlation between the real data and the results of models. The coefficient correlation is a number in range 0 to 1. The indicator of the comparison relationship is shown by the coefficient correlation value. A coefficient correlation is greater than 0.8 meaning a strong relationship and less than 0.5 is shown a weak relationship.

According to Figure 5.24, the regression line showed the slope value was 0.0287; the intercept value was 0.1179 and the determination coefficient (r^2) was 0.9443. According to r^2 value, the correlation coefficient (r) was 0.97 which implied that all types of measurements had strong relationship. Also the r value can be used to justify that the Q_{CWI} tool results are close to the real data (the construction waste model design) in terms of construction waste volume.

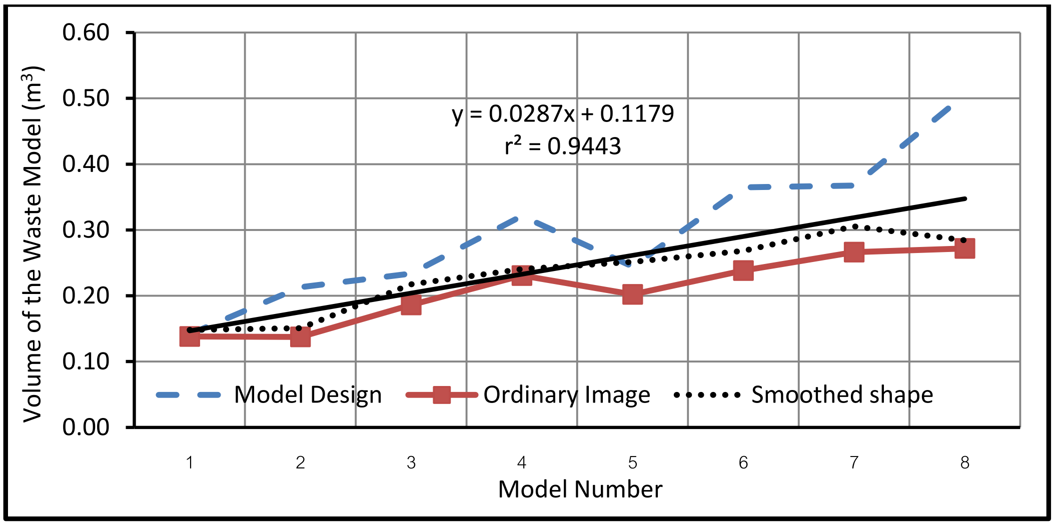


Figure 5.24 Differences of Volume Measuring of the Bricks Waste Model Based on the Design and the Q_{CWI} Tool

The results of the roof tiles waste model were similar to the bricks waste model. Volume measuring based on the Q_{CWI} tool was 0.239 m^3. The average of result was larger than the model design, 0.114 m^3. Comparison of volume measuring between the model design and the Q_{CWI} tool, the results of the ordinary image were larger than the results of the smoothed shape (0.128 m^3 > 0.100 m^3).

Table 5.10 Comparison of Volume Measuring of the Roof Tiles Waste Model between the Design and the Q_{CWI} Tool

No	Measurements of the Waste Model Using the Meter Tape			Measurements of the Waste Model Based on the Q_{CWI} Tool					
				Ordinary Image			Smoothed Shape		
	Width (cm)	Height (cm)	Volume (m^3)	Width (cm)	Height (cm)	Volume (m^3)	Width (cm)	Height (cm)	Volume (m^3)
1	100	47.83	0.16	103.00	45.51	0.16	117.45	43.71	0.20
2	125	43.62	0.23	113.03	44.90	0.19	119.72	44.00	0.21
3	125	48.14	0.25	114.21	48.25	0.21	123.53	49.14	0.25
4	150	46.81	0.35	116.19	42.38	0.19	121.51	40.57	0.20
5	125	41.16	0.21	114.23	47.52	0.21	133.71	44.12	0.26
6	150	51.36	0.39	123.94	45.57	0.23	128.91	45.36	0.25
7	150	54.40	0.41	125.34	48.10	0.25	133.90	47.90	0.29
8	175	59.63	0.61	131.26	51.34	0.29	136.29	49.59	0.31

Comparison of volume measuring based on the design and the Q_{CWI} tool were shown in Figure 5.25. The regression line is an indicator that the relation between both measurement methods is well associated. The equation y = 0.0271x + 0.141, wherein the slope was 0.027, the intercept value was 0.141, and the determination coefficient (r^2) was 0.853. The "r" value, 0.924 was less than the "r" value of the bricks waste models. Moreover, the correlation coefficient was close to 1 where the "r" as an indicator in both measurements was well associated.

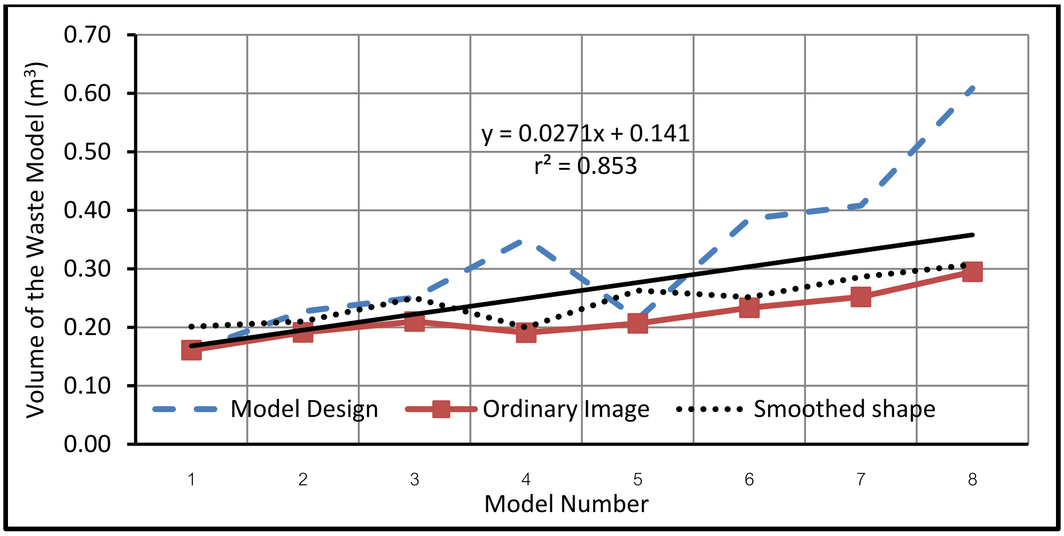


Figure 5.25 Differences of Volume Measuring of the Roof Tiles Waste Model Based on the Design and the Q_{CWI} Tool

Table 5.11 shows the comparison of volume measuring based on the concrete-mortar waste models and the Q_{CWI} tool. The average of volume was 0.247 m^3. Generally, the results were similar to the other waste models (bricks and roof tiles). The differences of volume of the waste models (number 1-5) were smaller (in average) than the large size waste models (number 6-8). According to the results, the ordinary images were larger than the smoothed shape. The differences of the volume between the two approaches were 0.0184 m^3, whereas the average results of the ordinary image were 0.238 m^3, and the smoothed shape were 0.256 m^3. The smallest difference was shown by the waste model number one, and the largest difference was shown by the model number eight. It indicated that the accuracy of the small sizes was better than the large size model. Nevertheless, the percentage error of the Q_{CWI} tool was acceptable.

Table 5.11 Comparison of Volume Measuring of the Concrete-Mortar Waste Model between the Design and the Q_{CWI} Tool

No	Measurements of the Waste Model Based on the Tape Meter			Measurements of the Waste Model Based on the Q_{CWI} tool					
				Ordinary Image			Smoothed Shape		
	Width (cm)	Height (cm)	Volume (m^3)	Width (cm)	Height (cm)	Volume (m^3)	Width (cm)	Height (cm)	Volume (m^3)
1	100	35.54	0.12	94.72	37.91	0.11	102.69	37.91	0.13
2	125	34.91	0.18	112.42	40.54	0.17	118.04	37.03	0.17
3	125	40.07	0.21	121.70	44.63	0.22	123.93	41.00	0.21
4	150	41.15	0.31	120.62	41.35	0.20	132.29	38.52	0.22
5	125	46.94	0.24	131.20	51.78	0.30	135.48	52.78	0.32
6	150	44.70	0.34	130.58	47.48	0.27	133.40	43.00	0.26
7	150	46.31	0.35	129.56	48.97	0.27	145.24	47.54	0.33
8	175	45.94	0.47	134.48	46.95	0.28	147.15	43.14	0.31

Figure 5.26 describes the levels of accuracy of the Q_{CWI} tool and the design of model. The regression line and the correlation coefficient are used as the indicator to evaluate the Q_{CWI} tool. The determination coefficient was 0.969 which mean that the correlation coefficient "r" value a s 0.984, which was close to 1. It was the larger value than the other models (bricks and roof tiles).

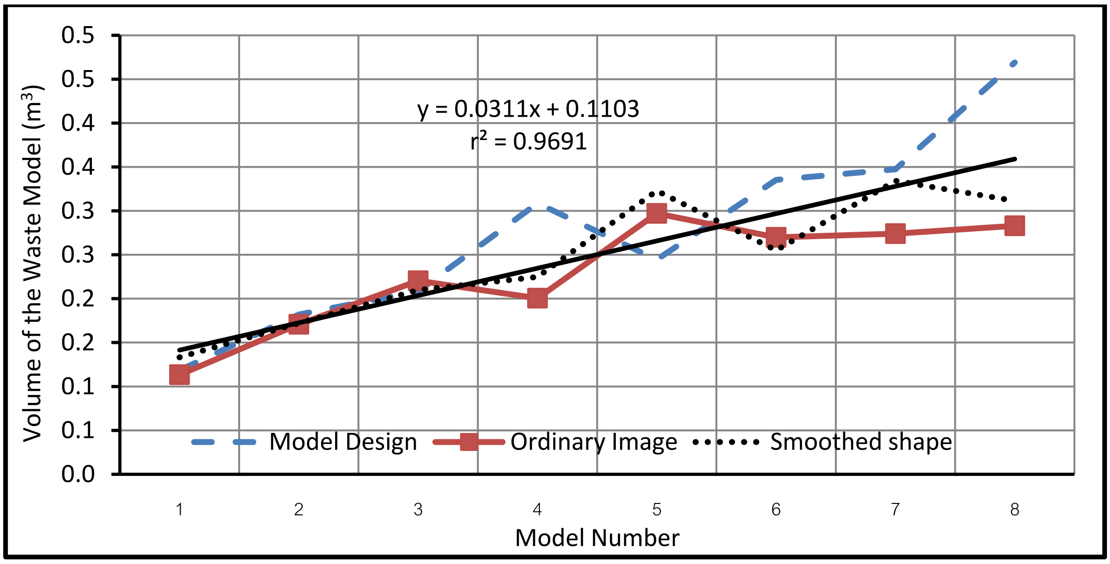


Figure 5.26 Differences of Volume Measurement of the Concrete-Mortar Waste Model Based on the Design and the Q_{CWI} Tool

5.4.2 Weight of the Construction Waste Model

The quantification of the construction waste model in terms of weight was the volume of the cone multiplied by the density of waste. For weight calculation, the density value of bricks was used 911 kg/cm^3, 717 kg /m^3 for roof tiles and 1,153 kg/m^3 for concrete-mortar. Table 5.12 to Table 5.14 described the weight of bricks, roof tiles and concrete-mortar were as follows.

Table 5.12 Comparison of Weight Measuring the Bricks Waste Model between the Balance Scale and the Q_{CWI} Tool

No	Measurements of the Waste Model Based on Balance Scale			Measurements of the Waste Model Based on the Q_{CWI} Tool					
				Ordinary Image			Smoothed Shape		
	Width (cm)	Height (cm)	Weight (Kg)	Width (cm)	Height (cm)	Weight (Kg)	Width (cm)	Height (cm)	Weight (Kg)
1	100	42.48	150	97.52	43.59	125.87	101.92	42.79	134.95
2	125	40.92	150	98.16	42.83	125.30	104.43	41.50	137.42
3	125	44.85	200	111.23	45.12	169.51	121.89	43.89	198.01
4	150	42.84	200	129.01	41.59	210.18	134.97	39.60	219.08
5	125	46.92	250	115.28	45.61	184.09	129.80	44.77	229.03
6	150	48.64	250	124.41	46.20	217.12	135.29	43.96	244.31
7	150	49.00	300	129.28	47.80	242.62	140.09	46.70	278.32
8	175	49.49	300	131.87	46.92	247.76	138.91	44.20	258.98

Table 5.12 showed comparison of the bricks waste model between the model design and the Q_{CWI} tool in terms of weight. In both approaches, the waste model number four was bigger than design of the waste model. The different of the ordinary image was 10.18 kg, which was smaller than that of the smoothed shape, 19.08 kg. According to the table 5.12, the differences of weight between the model design and the Q_{CWI} tool were in the range of 19.28 kg – 46.63 kg. The results showed the percentage errors of Q_{CWI} tool were in range of 6.43% - 15.54%.

Figure 5.27 showed the comparison between both methods. It indicated two measurements were agreed with one another. Furthermore, the regression line shows that the slope value was 20.945. The intercept value was 115.02, and the determination coefficient was 0.95. The correlation coefficient "r" justifies that both measurements were well associated because the r value was 0.975 close to 1.

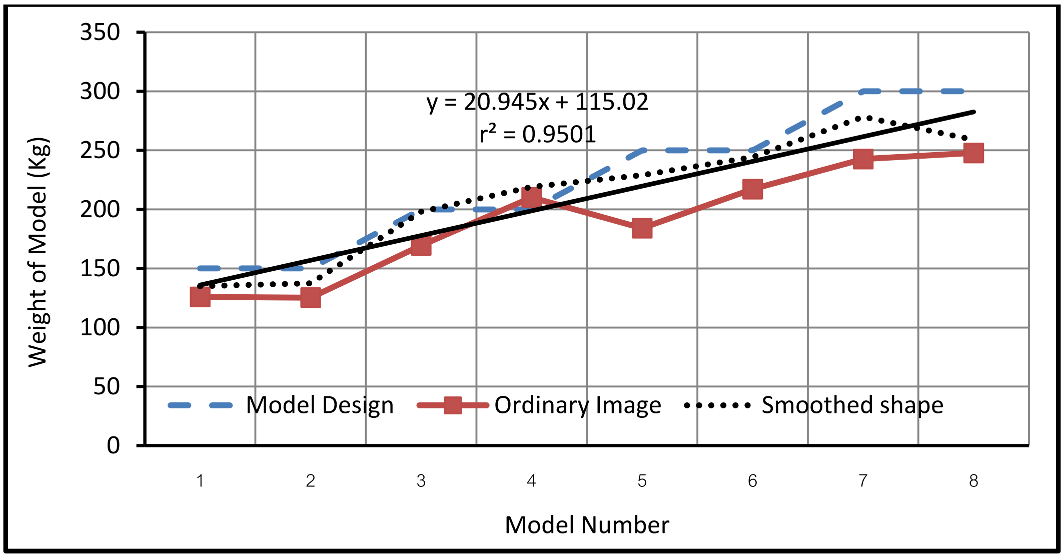


Figure 5.27 Differences of Weight Measuring of the Bricks Waste Model Based on the Balance Scale and the Q_{CWI} Tool

The results of the roof tiles model were different compared to the bricks model. The characteristic of the roof tiles material affected the density value. The density value of roof tiles was smaller than the bricks and the concrete mortar waste. The result of the Q_{CWI} tool showed that the weight was less than the real weight.

Table 5.13 Comparison of Weight Measuring the Roof Tile Waste Model between the Balance and the Q_{CWI} Tool

No	Measurements of the Waste Model Based on Balance Scale			Measurements of the Waste Model Based on the Q_{CWI} Tool					
				Ordinary Image			Smoothed Shape		
	Width (cm)	Height (cm)	Weight (Kg)	Width (cm)	Height (cm)	Weight (Kg)	Width (cm)	Height (cm)	Weight (Kg)
1	100	47.83	150	103.00	45.51	115.38	117.45	43.71	144.12
2	125	43.62	150	113.03	44.90	137.10	119.72	44.00	150.72
3	125	48.14	200	114.21	48.25	150.42	123.53	49.14	179.20
4	150	46.81	200	116.19	42.38	136.74	121.51	40.57	143.18
5	125	41.16	250	114.23	47.52	148.19	133.71	44.12	188.50
6	150	51.36	250	123.94	45.57	167.29	128.91	45.36	180.17
7	150	54.40	300	125.34	48.10	180.59	133.90	47.90	205.24
8	175	59.63	300	131.26	51.34	211.41	136.29	49.59	220.16

Figure 5.28 described the comparison of the roof tile waste model in terms of weight between the Q_{CWI} tool and the model design. Generally, the result showed the similarity trend with the other models, where the large size model gives large differences. Figure 5.28 showed the regression line of the difference of the weight, where the slope, the intercept and the determination coefficient (r^2) value were 15.098, 117.82 and 0.9342 respectively. The correlation coefficient "r" as 0.967 as the indicator that those types of measurement agree with one another. Roof tiles model number two had the closest gap. On the other hand, roof tiles waste model number eight showed the largest gap.

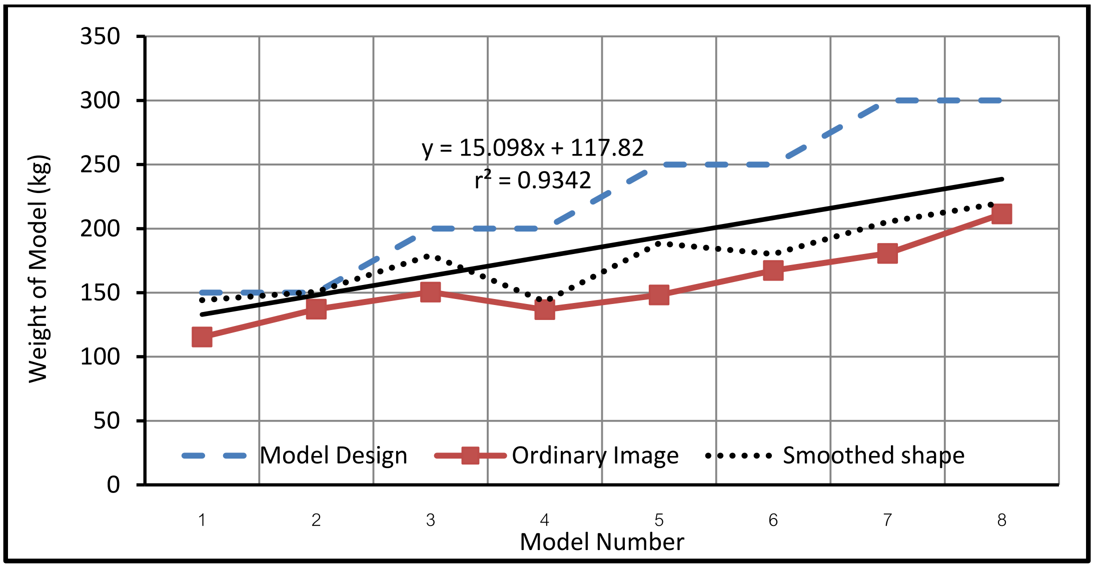


Figure 5.28 Differences between Weight Measuring of the Roof Tile Waste Model Based on the Balance Scale and the Q_{CWI} Tool

Table 5.14 illustrated comparison the concrete-mortar waste model in terms of weight between the Q_{CWI} tool and the design of model. The results were larger than the design. It was caused by the material characteristics. The differences between common waste materials and concrete-mortar materials lie on shape and size. They tend to be round and heavier, consequently they spread out of the base spot model. These conditions lead to an inaccurate calculation by using the density value. The waste model number one showed a close gap, with average of 11.47 kg or 11.47 %.

The biggest gap was shown by the model number five. Detailed illustration of the result of the concrete-mortar model was shown in Table 5.14 below.

Table 5.14 Comparison of Weight Measuring the Concrete-Mortar Waste Model between the Balance and the Q_{CWI} Tool

No	Measurements of the Waste Model Based on Balance			Measurements of the Waste Model Based on the Q_{CWI} tool					
				Ordinary photo			Smoothed shape		
	Width (cm)	Height (cm)	Weight (Kg)	Width (cm)	Height (cm)	Weight (Kg)	Width (cm)	Height (cm)	Weight (Kg)
1	100	35.54	150	94.72	37.91	130.71	102.69	37.91	153.64
2	125	34.91	150	112.42	40.54	196.93	118.04	37.03	198.29
3	125	40.07	200	121.70	44.63	254.07	123.93	41.00	242.00
4	150	41.15	200	120.62	41.35	231.20	132.29	38.52	259.08
5	125	46.94	250	131.20	51.78	342.53	135.48	52.78	372.32
6	150	44.70	250	130.58	47.48	311.14	133.40	43.00	294.08
7	150	46.31	300	129.56	48.97	315.96	145.24	47.54	385.36
8	175	45.94	300	134.48	46.95	326.33	147.15	43.14	359.01

According to Figure 5.29, waste model number six and four showed smaller differences than the other models. The gaps are 21 % and 22.5 %. The regression line showed that the slope was 27.339; the intercept was 134.17 and the determination coefficient was 0.8826. The coefficient correlation was 0.939 close to 1 indicating that both measurements had well relationship.

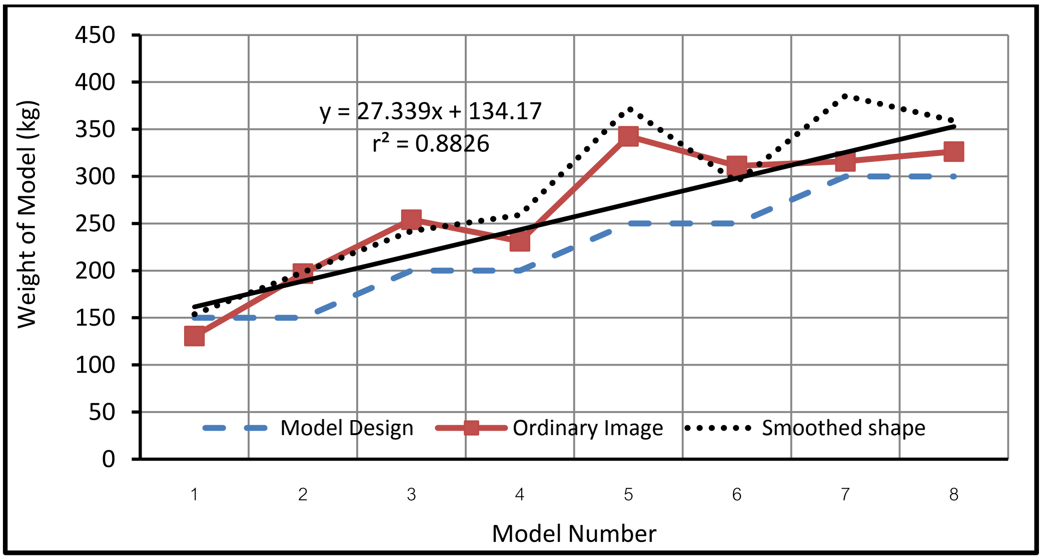


Figure 5.29 Differences of Weight Measuring the Concrete-Mortar Waste Model Based on the Balance Scale and the Q_{CWI} Tool

5.5. Improvement of the Q_{CWI} Tool

Furthermore, the research develops the Q_{CWI} tool for data acquisition. An alternative uses the external webcam for image capture. Moreover, improvement data analysis is also required to increase the accurate result. The Q_{CWI} tool proposes a new method to identify the object, and the data analysis is called "Area Method."

Area method calculates the waste quantification by dividing the waste stacks into the number of slices. The radius of area is identified based on coordinate, thus it could be calculated as equal as area. Volume of waste is calculated by the multiplication of area and the height of each slice. The total quantity of waste gained from the cumulative volume of two slices along the construction waste stack.

5.5.1 Improvement of the Data Input

The Q_{CWI} Tool proposes an alternative method for image capture using by a webcam. The user can use an external webcam to capture the waste at the construction site. Using the webcam, the user can reduce a time for data acquisition and data transfer. Illustration of the webcam program is shown in Figure 5.30 below.

Figure 5.30 The Webcam Program for Image Capture

5.5.2 An Alternative Method for Object Identification

The Q_{CWI} tool provides another method to identify an object by using the boundary method. The user can identify the object based on an outline shape of the waste stack. Contour of surface can be traced in detail by using a mouse. The expectation of this method is to increase the accuracy of the result. Illustration of the boundary method is shown in Figure 5.31 below. Moreover, the boundary method combined with mask technique and binary image can be used to identify the object clearly.

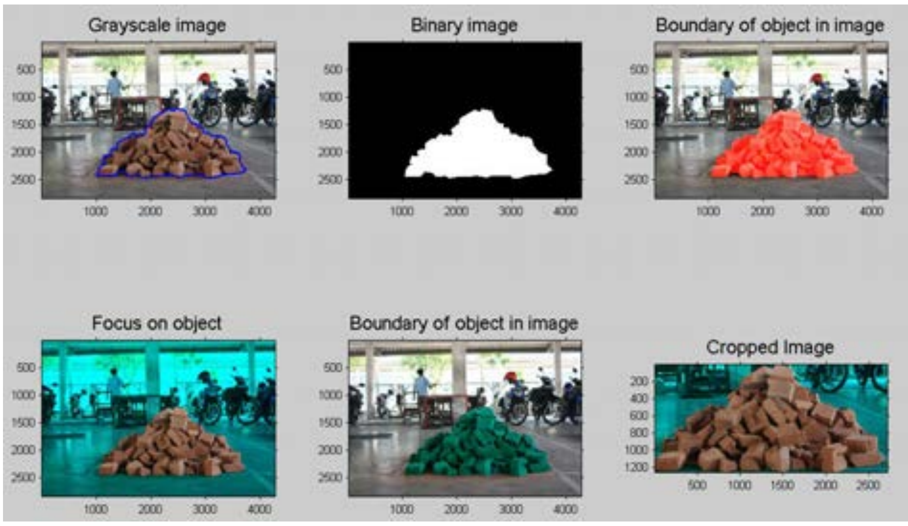


Figure 5.31 The Boundary Method

5.5.3 Analysis Data Based on the Boundary Image

Cropping technique and zooming are used to support the user to identify the object by tracing the outline of stack waste. Figure 5.32 show a process for image cropping and zooming for identification of an object.

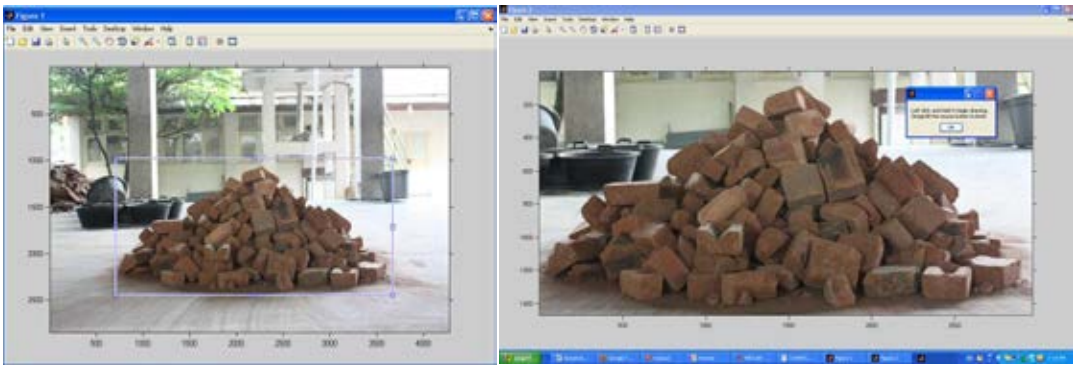


Figure 5.32 Cropping and Image Zooming

Volume of the waste stacks is identified based on the number of area in the waste stack. Each part is used to calculate area and volume, where the height and the width of each part are found based on the coordinates of each area. Volume of the area is the average of three images. The technique adopted from the polygon method, the user can track the contour of the waste stack by using mouse. Illustration of this method is shown in Figure 5.33 below.

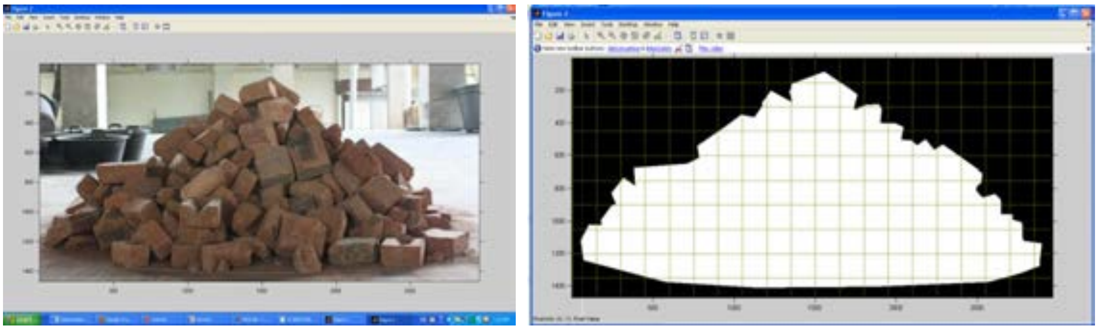


Figure 5.33 Binary Image of the Waste Stack

The slice of the waste stacks is created per 5 cm based on the grid lines on the image. Area of a slice is $A = \pi r^2$.

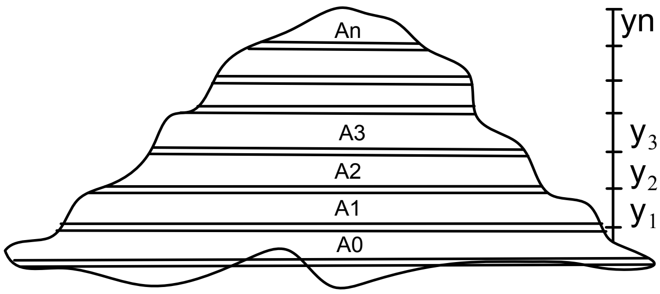


Figure 5.34 Slices of the Waste Stack Based on the Area Method

Volume of the waste stack is calculated based on formula below.

$$Volume = \sum\left(\frac{A0+A1}{2} \times y1\right) + \left(\frac{A1+A2}{2} \times y2\right) + \cdots + \left(\frac{A(n-1)+An}{2} \times yn\right) \quad \text{............(5.2)}$$

5.5.4 Quantification of Waste Based on the Area Method

The improvement of the quantification method was tested on the bricks waste model weighting 150 kg and 200 kg. Analysis of the result was done by comparing the design of the waste model in terms of volume and weight. Difference of the result was an indicator of the reliability of this method. Table 5.15 showed detail calculation of using the area method. Detailed calculation of this method was shown in appendix C.

Table 5.15 Quantity of the Stack Waste Based on the Area Method

No. of Slice	IMAGE 1 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)
	Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter		
	X	Y					X	Y					X	Y				
1	2825	1349	147	2784	0.0076	0.04037	2735	1304	102	2364	0.0055	0.02217	2861	1289	87	2814	0.0077	0.02446
	41	1352	153				371	1304	105				47	1289	93			
2	2846	1202	150	2805	0.0077	0.04035	2726	1202	150	2616	0.0067	0.03384	2855	1202	150	2802	0.0077	0.03724
	41	1199	147				110	1199	147				53	1196	147			
3	2891	1052	150	2811	0.0077	0.03707	2567	1052	150	2526	0.0062	0.03179	2858	1052	150	2589	0.0065	0.03171
	80	1052	150				41	1052	150				269	1049	147			
4	2663	902	150	2538	0.0063	0.02838	2543	902	150	2433	0.0058	0.02552	2732	902	150	2385	0.0056	0.02683
	125	902	150				110	902	147				347	902	150			
5	2441	752	150	2130	0.0044	0.01955	2303	752	150	2013	0.004	0.01857	2669	752	150	2166	0.0046	0.0202
	311	752	147				290	755	153				503	752	150			
6	2234	602	150	1761	0.003	0.01128	2213	602	150	1749	0.003	0.01307	2444	602	150	1767	0.0031	0.0115
	473	605	153				464	602	150				677	602	150			
7	1820	452	150	1104	0.0012	0.00436	1979	452	150	1413	0.002	0.00673	2171	452	150	1152	0.0013	0.00465
	716	452	147				566	452	150				1019	452	150			
8	1724	302	264	696	0.0005	0.00222	1643	302	273	780	0.0006	0.00286	1877	302	288	687	0.0005	0.00234
	1028	305	267				863	302	273				1190	302	288			
Height	**1352**	**1334**	**1312.5**	**T O T A L**	**0.0048**	**0.18358**	**1352**	**1325**	**1275**	**T O T A L**	**0.0042**	**0.15455**	**1652**	**1283**	**1275**	**T O T A L**	**0.0046**	**0.15893**
	1355	**38**	**1296**				**1352**	**29**	**1296**				**1649**	**14**	**1269**			

Material type = **Brick** **Density =** **911 kg/m^3**

Average of Volume = **0.1657 m^3**

Weight of the waste stack = **150.94 kg**

5.5.5 Results of the Area Method

Comparison of volume and weight measuring based on design of the brick waste model was done with 150 kg of weight and 100 cm. of base width. It was shown in Table 5.16 below.

Table 5.16 Comparison of the Waste Quantification for the Bricks Waste Model, (Weight: 150 kg, Width of Base: 100 cm)

Image Number	Design of the Construction Waste Model		Measurement Based on the Q_{CWI} Tool		Differences of Measurement Based on the Design and the Q_{CWI} Tool		Absolute of the Percentage Error	
	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume	Weight
1	0.165	150	0.166	151.46	-0.001	-1.46	0.82	0.97
2	0.165	150	0.164	149.85	0.001	0.15	0.40	0.10
3	0.165	150	0.161	146.68	0.004	3.32	2.22	2.21
4	0.165	150	0.156	142.78	0.009	7.22	5.26	4.81
5	0.165	150	0.157	143.18	0.008	6.82	4.65	4.55
6	0.165	150	0.161	146.73	0.004	3.27	2.22	2.18
7	0.165	150	0.16	145.92	0.005	4.08	2.83	2.72
8	0.165	150	0.165	150.22	0.000	-0.22	0.21	0.15
9	0.165	150	0.157	143.55	0.008	6.45	4.65	4.30
10	0.165	150	0.165	150.94	0.000	-0.94	0.21	0.63

According to Table 5.16, the mean of weight measuring with the area method was 147.13 kg and the deviation standard was 3.32. For measurement of volume, the mean was 0.161 m^3 and the deviation standard was 0.004. According to the result, the area method showed a good result. Comparison details of different measurements were as follows. The greatest gap of volume was 0.009 m^3 or 5.26%. The smallest gap showed by model number ten. For weight, the differences of 7.22 kg (4.81%) and 0.15 kg (0.1%) were the greatest and smallest gap respectively. Figure 5.35 illustrates the differences of measurements. Both measurements showed well associated.

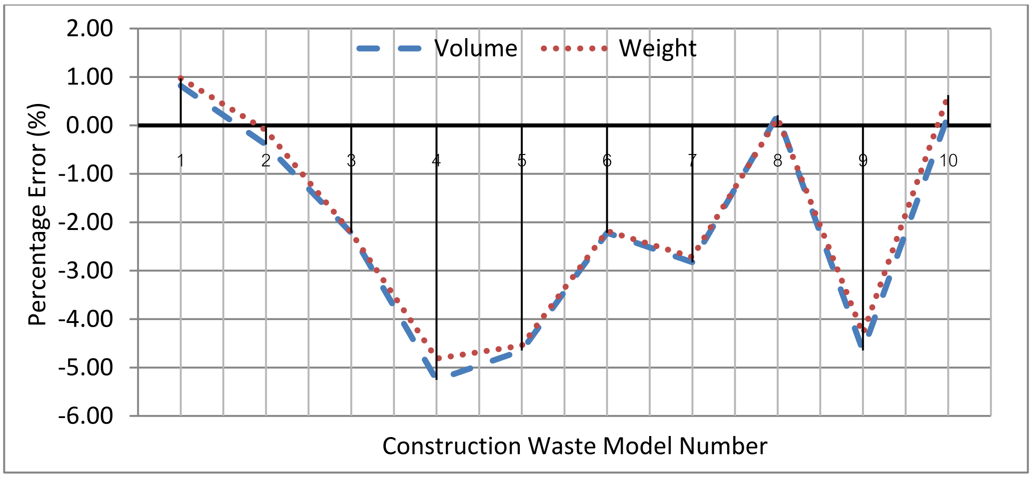


Figure 5.35 Differences of Weight and Volume Measuring the Bricks Waste (Weight: 150 kg, Width of Base: 100 cm)

Table 5.17 below showed the result for the bricks waste model with weight of 150 kg and base width of 125 cm. The results of this model showed that the mean of weight was 150.26 kg and the deviation standard was 9.62. For volume measuring, the mean was 0.165 m^3 and the deviation standard was 0.01.

Table 5.17 Comparison of the Waste Quantification for the Bricks Waste Model, (Weight: 150 kg, Width of Base: 125 cm)

Image Number	Design of Construction Waste Model		Measurement Based on the Q_{CWI} Tool		Differences of Measurement Based on Design of the Model and the Q_{CWI} Tool		Absolute of the Percentage Error	
	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume	Weight
1	0.165	150	0.157	143.52	0.008	6.48	4.65	4.32
2	0.165	150	0.177	161.56	-0.012	-11.56	7.50	7.71
3	0.165	150	0.165	150.43	0.000	-0.43	0.21	0.29
4	0.165	150	0.169	154.22	-0.004	-4.22	2.64	2.81
5	0.165	150	0.161	146.74	0.004	3.26	2.22	2.17
6	0.165	150	0.174	158.61	-0.009	-8.61	5.68	5.74
7	0.165	150	0.169	154.65	-0.004	-4.65	2.64	3.10
8	0.165	150	0.148	134.78	0.017	15.22	10.11	10.15
9	0.165	150	0.177	161.29	-0.012	-11.29	7.50	7.53
10	0.165	150	0.150	136.82	0.015	13.18	8.90	8.79

Difference of volume measuring was 0.017m^3(10.11%), the maximum gap. Minimum gap is equal to 0 m^3. Maximum gap of weight measuring was 15.22 kg

(10.15%), and minimum was 0.21 kg (0.29%). Figure 5.36 illustrates the comparison between two measurements.

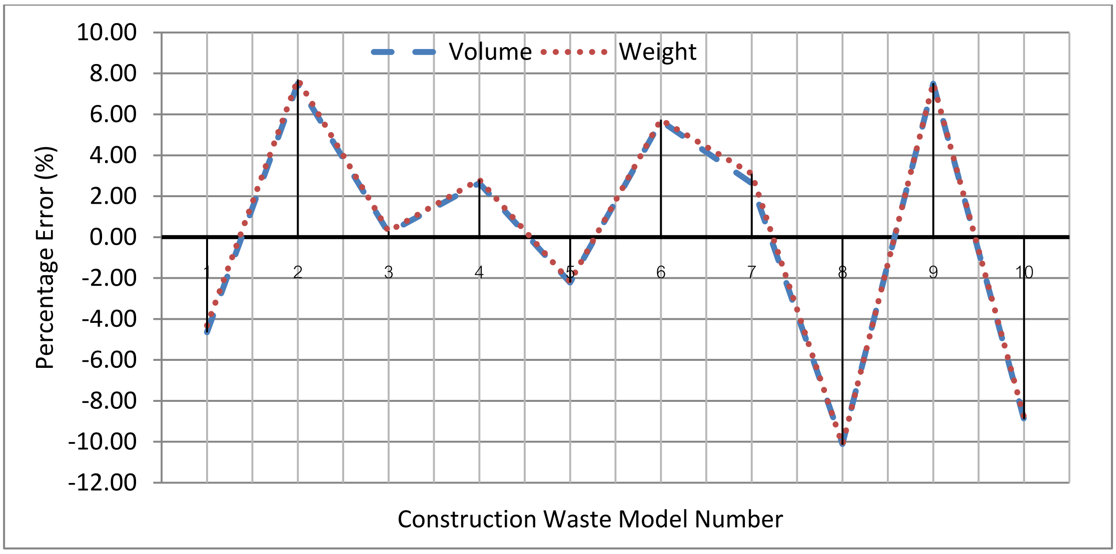


Figure 5.36 Differences of Weight and Volume Measuring the Bricks Waste (Weight: 150 kg, Width of Base: 100 cm)

Comparison of the waste quantification in terms of volume and weight for the brick model, (weight: 200 kg and width of base: 125 cm) were shown in Table 5.18. The mean of weight measurement was 188.32 kg. The deviation standard was 14.13. For volume measuring, the mean was 0.21 m^3 and the deviation standard was 0.016. According to the result, comparison with the previous result, it showed the increasing gap in the big size sample.

Details of comparison show that the maximum gap of weight was 31.83 kg (15.92 kg), and a minimum gap was 2.44 kg (1.22%). For volume, a maximum gap was 0.04 m^3 (18.01%), and minimum gap was 0.01 m^3 (4.35%). According to the mean and the deviation standard, the area method contributes convergent value.

Table 5.18 Comparison of the Waste Quantification for the Bricks Waste Model, (Weight: 200 kg, Width: of Base 125 cm)

Image Number	Design of Construction Waste Model		Measurement Based on the Q_{CWI} Tool		Differences of Measurement Based on the Design and the Q_{CWI} Tool		Absolute of the Percentage Error	
	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume	Weight
1	0.220	200	0.18	168.17	0.040	31.83	18.01	15.92
2	0.220	200	0.19	176.63	0.030	23.37	13.46	11.69
3	0.220	200	0.21	189.3	0.010	10.7	4.35	5.35
4	0.220	200	0.2	182.68	0.020	17.32	8.90	8.66
5	0.220	200	0.21	194.27	0.010	5.73	4.35	2.86
6	0.220	200	0.21	197.56	0.010	2.44	4.35	1.22
7	0.220	200	0.2	184.11	0.020	15.89	8.90	7.94
8	0.220	200	0.23	205.46	-0.010	-5.46	4.77	2.73
9	0.220	200	0.23	211.91	-0.010	-11.91	4.77	5.96
10	0.220	200	0.190	173.1	0.030	26.9	13.46	13.45

Figure 5.37 showed the comparison between two type measurements. The maximum gap was shown by model number one and the minimum gap was shown in model number six. According to the amount of gaps, the area method indicated that the method was accurate in an acceptable range.

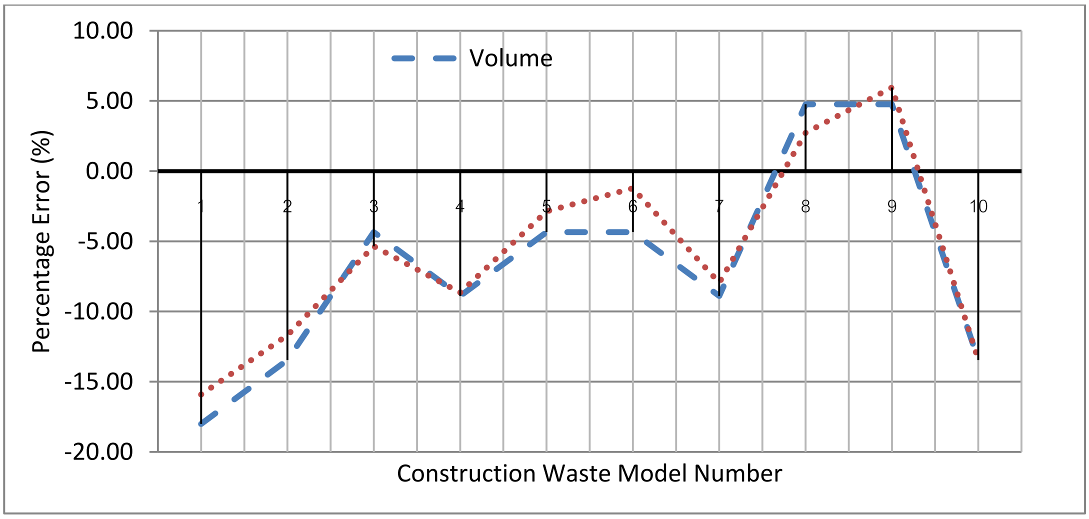


Figure 5.37 Differences of Weight and Volume Measuring the Bricks Waste (Weight: 200 kg, Width of Base: 125 cm)

The results for the brick waste model with weight of 200 kg and base width of 150 cm were shown in Table 5.19. For weight measuring, the mean was 203.21 kg, and the deviation standard was 16.37. The result presented that the wider models showed a greater gap than the small models. In volume measuring, the mean of a result was 0.22 and the deviation standard was 0.019. These results of volume measuring were similar.

Table 5.19 Comparison of the Waste Quantification for the Bricks Waste Model, (Weight: 200 kg, Width of Base: 150 cm)

Image Number	Design of Construction Waste Model		Measurement Based on the Q_{CWI} Tool		Differences of Measurement Based on the Design and the Q_{CWI} Tool		Absolute of the Percentage Error	
	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume (m^3)	Weight (kg)	Volume	Weight
1	0.220	200	0.000	-0.67	0.21	0.33	0.21	0.33
2	0.220	200	-0.030	-24.91	13.88	12.46	13.88	12.46
3	0.220	200	0.030	20.08	-13.46	-10.04	13.46	10.04
4	0.220	200	-0.020	-18.97	9.32	9.49	9.32	9.49
5	0.220	200	-0.010	-11.05	4.77	5.53	4.77	5.53
6	0.220	200	0.000	-1.8	0.21	0.90	0.21	0.90
7	0.220	200	0.000	0.59	0.21	-0.30	0.21	0.30
8	0.220	200	0.000	-2.89	0.21	1.44	0.21	1.44
9	0.220	200	0.030	25.74	-13.46	-12.87	13.46	12.87
10	0.220	200	-0.010	-18.25	4.77	9.13	4.77	9.13

Figure 5.38 provides information related to the differences of the Q_{CWI} tool measurement compared with the design of waste model.

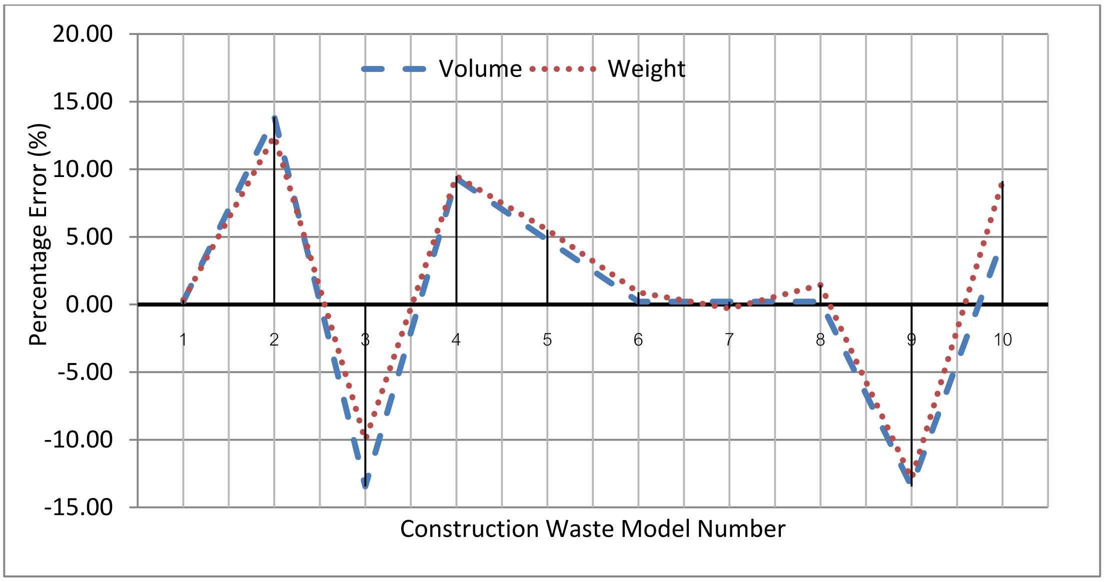


Figure 5.38 Differences between Weight and Volume Measuring the Bricks Waste (Weight: 200 kg, Width of Base: 150 cm)

5.6. Comparing the Q_{CWI} Tool with the Artificial Neural Network

This research also compares the Q_{CWI} tool with the artificial neural network (ANN) program. The comparison identifies the advantages and disadvantages of the Q_{CWI} tool. The comparison focuses on the operation of program and the preparation of the data input. ANN imitates the learning process of human brain and it can process a problem involving non-linear and complex data even if the data are imprecise and un-correlation. The advantage of ANN is being able to obtain an accurate output even if the variables among interactions are not absolutely understandable. ANN is not a newest method, but it can overcome the problem easier and faster than some other methods according to the number of data, the correlation between input-output, etc. It is a powerful tool for modeling, especially when the underlying data relationship is indefinite. ANN can identify and learn a pattern between input data sets and had been proved target values. According to the training session, ANN can be used to predict the outcome of new independent input data.

According to the characteristic of data input and the target/output in the waste quantification system, ANN is capable to use for estimate waste quantification in terms volume and weight. This research uses number of boxes, which are overlapping between object and gridlines as data input. The output is the quantity of waste in terms of volume (m^3) and weight (kg). According to data input and output, this research initiates to compare the process between two methods. Training supports technique the ANN program to know the data input, parameter and the output. Number of data for training influences the accuracy of result. In this section, this research uses the commercial software, Qnet 2000. The data are divided into three groups for training, test and validation.

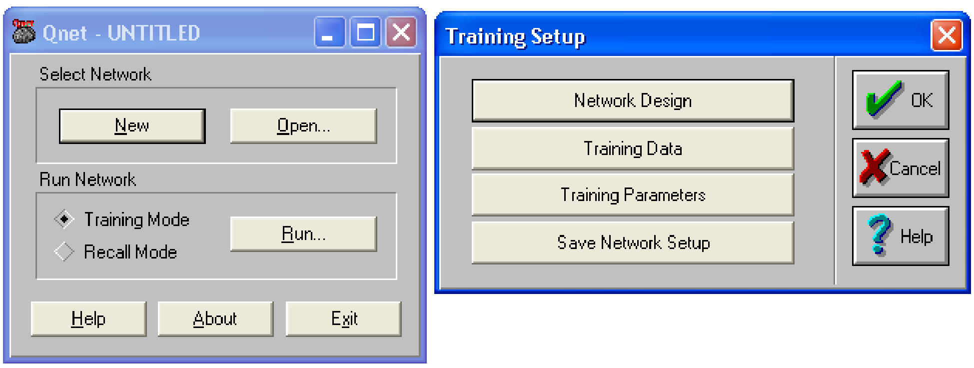


Figure 5.39 Qnet 2000 Program

The program consists of three modules, network setup, data input and training parameter. Illustration of modules is shown in Figure 5.40 below.

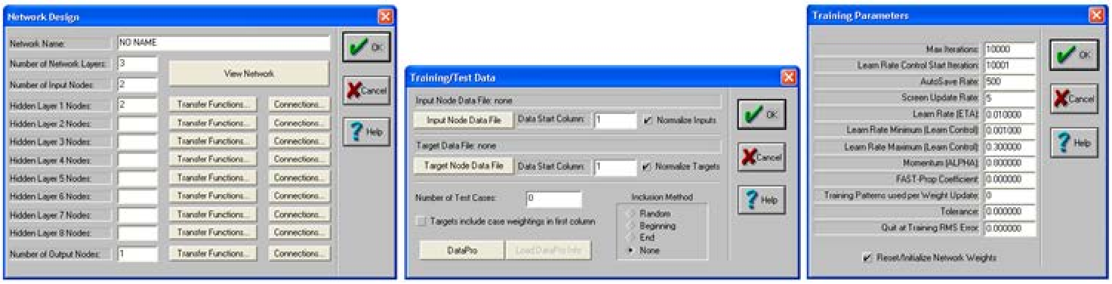


Figure 5.40 Qnet Modules

5.6.1 Network Setup

Figure 5.41 shows the network setup of the artificial neural network. In this case the network consists of three layers, input layer, hidden layer and output layer. Data input has three images from different sides, thus the input layers consist of three nodes. The hidden layer is constructed by six nodes, and the output layer is a single node that represents the weight or volume of construction waste. The transfer function is the sigmoid function. The sigmoid function is represented by the mathematical relationship as $\frac{1}{1+e^{-1}}$. Generally, the output response of node is a certain value between 0 and 1.

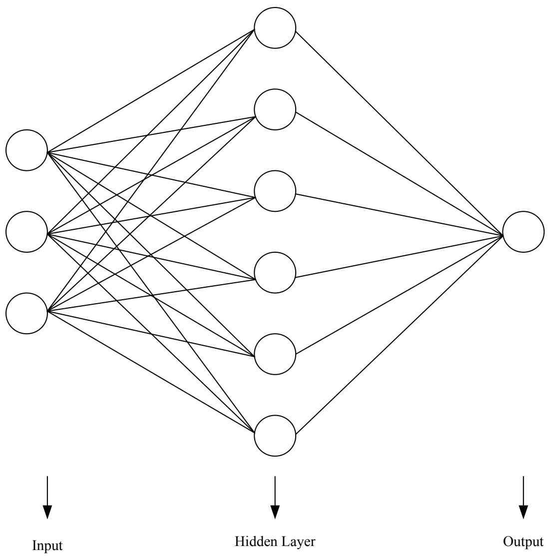


Figure 5.41 Network Design

5.6.2 Data Input

The quantification of construction waste network is arranged to connect the data input through the hidden layer with some parameters to find the target. Inputs are entered into the input neurons, and the hidden layer setup with the certain parameters, and transferred to the output. The network of program is trained by establishing the weighted connections between the input nodes and the output via the hidden neurons.

Q2000 provides menus for data input, which is compatible to *ASCII* file format. It also provides the data pro menu to create a new data. The data are arranged in column and row format whereas the input and the output are separated based on the number of data column. In this part, the data for the training and the test run are separated, which is 70 % for training and 30 %, is for testing. For validation, another set of different data is used.

5.6.3 Training Parameter

The Qnet 2000 provides the menu for training parameters. The important menu is adopted from the manual of Qnet 2000.

5.6.3.1 Number of Iterations

The number of iterations gives impact to output of network. It is important in training session. The maximum iterations can be extended to reach the prior iteration to adequate convergence. In this case, the number of iterations is 10000.

5.6.3.2 Learn Rate Control (LRC)

Learn Rate control is to control the divergence of output in training session. This algorithm will seek the optimal learning rate range during the training run. Learning rate in Qnet 2000 consists of three types of learning rate. They are ETA, minimum learning rate and maximum learning rate. ETA determines the size of the weights node adjustment during training. The valid range of ETA is between 0.0 and 1.0. While higher ETA results in faster learning, it can also lead to training instabilities and divergence. For initial training, a value in the range of 0.001 to 0.1 is used. Minimum and maximum learning rates are as threshold values to control and avoid instabilities of learning rate in training session.

5.6.3.3 AutoSave Rate

AutoSave Rate is a menu to assist the user to save the network during training session. The user can setup AutoSave by considering the number of data in training session.

5.6.3.4 Momentum Factor (Alpha)

In this process, algorithms are used to obtain the coefficient. It is set in the range of 0.8 to 0.9.

5.6.3.5 FAST-Prop Coefficient

The FAST-Propagation coefficient controls the algorithm used by Qnet 2000 for training. FAST-Propagation training can accelerate training for some networks and one can switch between FAST-Propagation and back propagation methods during training. Qnet 2000 will employ its back propagation algorithm to train the network, if the coefficient is set to a value above 0.0 (to a maximum of 3.0).

5.6.4 Training and Testing Results

The data for ANN were provided based on image processing by simple technique through putting grids (boxes) on the image. The size of box was 1.5 cm x 1.0 cm. Figure 5.42 shows adding grids (boxes) on image. The numbers of boxes were as data input.

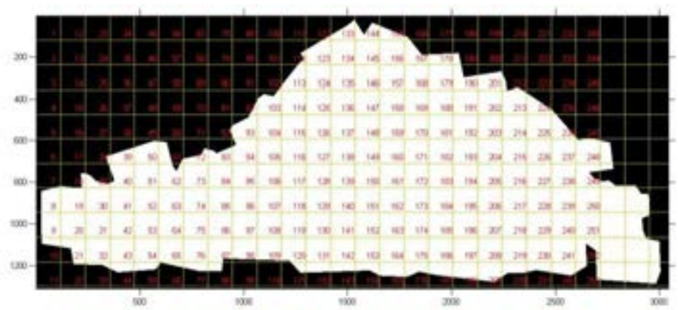


Figure 5.42 Grid Lines Extracting on Image

5.6.4.1 Identification Weight of Construction Waste using ANN

The total number of grids (boxes) on every image was reflected as input of network. Each of the construction waste model consisted of three images, thus data input was total number of boxes on each image. Sample of input data and target was shown in Figure 5.43 below. Column one to three show input data and the last column shows the target of networks. Table 5.20 showed the results of ANN in terms of weight.

```
240.000000,250.000000,250.000000,150.000000
248.000000,278.000000,253.000000,150.000000
251.000000,243.000000,243.000000,150.000000
269.000000,265.000000,277.000000,200.000000
280.000000,259.000000,263.000000,200.000000
279.000000,273.000000,285.000000,200.000000
267.000000,277.000000,263.000000,200.000000
```

Figure 5.43 Input and Target of Data for Weight of Construction Waste

Table 5.20 The ANN Results in Terms of Weight, Kg

No	Target	Output	Error	No	Target	Output	Error	No	Target	Output	Error
1	150	173.67	15.78	31*	200	155.17	3.45	61*	250	238.28	4.69
2*	150	164.10	9.40	32*	200	197.42	1.29	62*	250	235.15	5.94
3	150	137.13	8.58	33*	200	211.80	5.90	63*	250	211.00	15.60
4	150	142.17	5.22	34*	200	215.72	7.86	64*	250	231.27	7.49
5	150	143.27	4.49	35*	200	183.81	8.10	65	250	215.31	**13.88**
6*	150	134.02	10.65	36*	200	223.52	11.76	66*	250	238.86	4.46
7	150	149.57	0.29	37	200	206.92	3.46	67*	250	239.02	4.39
8	150	157.02	4.68	38*	200	217.93	8.96	68	250	234.94	6.02
9*	150	136.17	9.22	39*	200	226.21	13.10	69	250	237.83	4.87
10	150	141.95	5.37	40*	200	201.88	**0.94**	70*	250	233.68	6.53
11*	150	188.29	**25.53**	41*	200	162.21	18.90	71	250	204.63	18.15
12*	150	149.79	0.14	42*	200	195.50	2.25	72*	250	217.23	13.11
13*	150	160.90	7.27	43*	200	185.60	7.20	73	250	235.27	5.89
14*	150	160.74	7.16	44	200	213.05	6.53	74	250	217.98	12.81
15*	150	133.15	11.24	45*	200	230.37	15.18	75*	250	216.03	13.59
16	150	152.83	1.89	46	200	207.21	3.61	76*	250	231.43	7.43
17	150	153.34	2.23	47*	200	213.28	6.64	77	250	216.08	13.57
18*	150	144.17	3.89	48*	200	209.40	4.70	78*	250	235.12	5.95
19	150	149.82	**0.12**	49	200	240.29	20.15	79	250	227.34	9.07
20	150	155.17	3.45	50*	200	171.22	14.39	80*	250	222.84	10.86
21*	150	188.29	**25.53**	51*	200	177.36	11.32	81	250	251.22	0.49
22	150	149.79	0.14	52*	200	195.50	2.25	82*	250	249.43	**0.23**
23*	150	160.90	7.27	53	200	185.60	7.20	83	250	251.27	0.51
24	150	160.74	7.16	54*	200	213.05	6.53	84	250	255.49	2.19
25*	150	133.15	11.24	55*	200	230.37	15.18	85*	250	251.88	0.75
26*	150	152.83	1.89	56*	200	207.21	3.61	86	250	253.62	1.45
27*	150	153.34	2.23	57	200	213.28	6.64	87	250	252.55	1.02
28*	150	144.17	3.89	58*	200	209.40	4.70	88	250	252.65	1.06
29*	150	149.82	**0.12**	59	200	240.29	**20.15**	89*	250	236.44	5.42
30	150	173.67	15.78	60	200	171.22	14.39	90*	250	247.88	0.85

**) Data for testing*

The number of data was ninety data of images of the construction waste models. The data for testing were thirty-six and the rest was for training. The network statistic of ANN was shown in Figure 5.44 below. The maximum error for the training and testing were 40.29 and 45.36 respectively. Table 5.16 showed the result of ANN, which compares the target and output. The maximum error was 25.53 %, and the minimum was 0.12 %. According to the result, the average error was 7.35 and the deviation standard was 5.8.

Network Statistics

Network Name: Weight of waste
Iterations: 10000

TRAINING DATA:

Node	Std Dev	Bias	Max Error	Correlation
1	18.95599	-0.57611	40.29071	0.88303

TEST DATA:

Node	Std Dev	Bias	Max Error	Correlation
1	18.30652	-7.87185	45.36644	0.91788

Figure 5.44 The Network Statistics for the Weight of Construction Waste

5.6.4.2 Volume of Construction Waste

The neural network for the construction waste volume was designed in line with the weight of construction. The network statistic of ANN was shown in Figure 5.45 below. The maximum error for training and testing was 0.11. The maximum error of volume was less than that of the weight and also the correlation for training data and testing session was less than that of the weight correlation.

Network Statistics

Network Name: Volume of waste
Iterations: 10000

TRAINING DATA:

Node	Std Dev	Bias	Max Error	Correlation
1	0.04692	-0.00058	0.11410	0.67112

TEST DATA:

Node	Std Dev	Bias	Max Error	Correlation
1	0.05317	-0.01178	0.11385	0.60135

Figure 5.45 The Network Statistics for the Volume of Construction Waste

Table 5.21 shows the results of ANN, which the maximum error was 64.71 % and the minimum was 0.0 %. The average of percentage error was 18.63 and the deviation standard was 14.39. The percentage error for volume measuring was greater than that of the weight, and the output of the weight network was more convergent than the volume output. Also the accuracy of the weight was better than the volume. To ensure that the ANN method was more accurate than the Q_{CWI} tool, this research compared both the results in section 5.6.6.

Table 5.21 The ANN Results in Terms of Volume, m^3

No	Target	Output	Error	No	Target	Output	Error	No	Target	Output	Error
1	0.16	0.22	37.50	31	0.22	0.23	4.55	61*	0.27	0.28	3.70
2	0.16	0.21	31.25	32*	0.22	0.27	22.73	62*	0.27	0.26	3.70
3	0.16	0.15	6.25	33	0.22	0.25	13.64	63*	0.27	0.23	14.81
4*	0.16	0.16	**0.00**	34	0.22	0.23	4.55	64*	0.27	0.25	7.41
5	0.16	0.18	12.50	35	0.22	0.27	22.73	65	0.27	0.25	7.41
6	0.16	0.14	12.50	36	0.22	0.25	13.64	66	0.27	0.28	3.70
7	0.16	0.17	6.25	37*	0.22	0.27	22.73	67	0.27	0.27	**0.00**
8	0.16	0.18	12.50	38	0.22	0.28	27.27	68*	0.27	0.27	**0.00**
9	0.16	0.14	12.50	39*	0.22	0.23	4.55	69	0.27	0.26	3.70
10	0.16	0.16	0.00	40	0.22	0.19	13.64	70	0.27	0.26	3.70
11	0.21	0.21	**0.00**	41	0.28	0.22	21.43	71*	0.35	0.25	28.57
12*	0.21	0.17	19.05	42*	0.28	0.19	32.14	72	0.35	0.27	22.86
13	0.21	0.16	23.81	43	0.28	0.23	17.86	73	0.35	0.28	20.00
14	0.21	0.19	9.52	44*	0.28	0.24	14.29	74	0.35	0.26	25.71
15	0.21	0.14	33.33	45	0.28	0.25	10.71	75*	0.35	0.24	**31.43**
16*	0.21	0.17	19.05	46	0.28	0.25	10.71	76*	0.35	0.26	25.71
17*	0.21	0.16	23.81	47	0.28	0.25	10.71	77	0.35	0.26	25.71
18	0.21	0.16	23.81	48	0.28	0.28	**0.00**	78	0.35	0.29	17.14
19	0.21	0.18	14.29	49	0.28	0.22	21.43	79*	0.35	0.27	22.86
20	0.21	0.19	9.52	50	0.28	0.20	28.57	80	0.35	0.27	22.86
21	0.13	0.21	**61.54**	51	0.17	0.22	29.41	81*	0.22	0.22	**0.00**
22	0.13	0.17	30.77	52	0.17	0.19	11.76	82	0.22	0.20	9.09
23	0.13	0.16	23.08	53*	0.17	0.23	35.29	83*	0.22	0.21	4.55
24*	0.13	0.19	46.15	54	0.17	0.24	41.18	84*	0.22	0.22	**0.00**
25	0.13	0.14	7.69	55	0.17	0.25	47.06	85*	0.22	0.21	4.55
26	0.13	0.17	30.77	56*	0.17	0.25	47.06	86	0.22	0.21	4.55
27	0.13	0.16	23.08	57	0.17	0.25	47.06	87	0.22	0.20	9.09
28*	0.13	0.16	23.08	58	0.17	0.28	**64.71**	88	0.22	0.22	**0.00**
29	0.13	0.18	38.46	59	0.17	0.22	29.41	89	0.22	0.24	9.09
30*	0.13	0.19	46.15	60	0.17	0.20	17.65	90	0.22	0.26	18.18

**) Data for testing*

5.6.5 Validation of the Results

ali dation of the A net ork is using “ net tool.” Menu of program was shown in Figure 5.46 below. The validation process was similar to the training session. Firstly, the number of boxes from three images was as input data.

Then open the net ork system through “ pen net net or k” menu. The weight or the volume of construction waste came up on “the recall answer screen." The validation used new set of data. In this case, the number of validation data was forty.

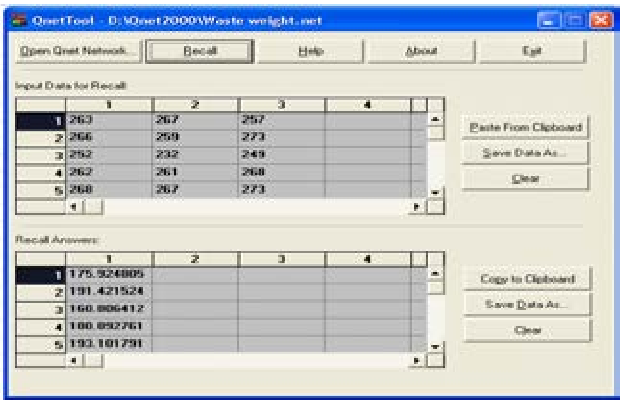


Figure 5.46 Qnet Tool

The result of validation was shown in Table 5.22 below. The neural network can identify the weight and volume of construction waste based on number of boxes from three images.

Table 5.22 Validation of the ANN Results

No	Input			Output		No	Input			Output	
	I	II	III	Weight	Volume		I	II	III	Weight	Volume
1	263	267	257	175.92	0.23	21	238	237	226	138.99	0.14
2	266	259	273	191.42	0.23	22	252	264	244	153.63	0.19
3	252	232	249	160.81	0.17	23	248	246	244	151.25	0.17
4	262	261	268	180.89	0.22	24	241	224	239	145.12	0.14
5	268	267	273	193.10	0.24	25	230	230	239	137.00	0.13
6	252	274	251	154.59	0.20	26	243	254	244	144.99	0.16
7	258	230	260	176.67	0.19	27	231	228	252	139.71	0.13
8	242	255	257	147.33	0.16	28	235	240	241	139.44	0.14
9	248	256	250	151.81	0.18	29	246	234	248	151.83	0.16
10	256	254	260	167.85	0.20	30	234	241	231	137.24	0.14
11	300	282	284	237.83	0.30	31	240	219	226	141.83	0.14
12	285	281	284	221.85	0.28	32	235	266	277	144.60	0.15
13	284	268	288	225.05	0.27	33	287	276	275	222.65	0.28
14	281	297	279	210.20	0.28	34	278	252	256	207.04	0.26
15	297	285	283	234.27	0.30	35	273	260	276	205.44	0.25
16	319	302	317	250.10	0.30	36	265	267	279	190.49	0.23
17	276	282	263	198.90	0.27	37	278	257	262	208.50	0.26
18	290	287	282	226.06	0.29	38	268	259	262	189.67	0.24
19	283	284	266	211.42	0.28	39	268	264	280	197.30	0.23
20	295	307	309	233.68	0.28	40	281	263	267	214.10	0.27

5.6.6 Comparison Results between ANN and the Q_{CWI} Tool

The comparison between ANN and the Q_{CWI} tool were grouped based on weight and volume of construction waste. Table 5.23 and Table 5.24 show the different results of the waste weight obtained from ANN and the Q_{CWI} tool. Generally, the ANN results were better than the Q_{CWI} tool based on average of the percentage error and the deviation standard. The average of percentage error from ANN was about 6.65 smaller than 8.48 of the tool, 8.48 and the standard deviation of ANN output was greater than that of the Q_{CWI} tool (6.48 > 5.66).

Table 5.23 Comparison the Weight of Waste between ANN and the Q_{CWI} Tool (150 kg)

No	Weight Target (kg)	Results of the ANN	Results of the Q_{CWI} Tool	Percentage Error of the ANN	Percentage Error of the Q_{CWI} Tool
1	150	173.67	120.84	15.78	19.44
2	150	164.10	158.46	9.40	5.64
3	150	137.13	125.20	8.58	16.53
4	150	142.17	122.08	5.22	18.61
5	150	143.27	125.03	4.49	16.65
6	150	134.02	116.55	10.65	22.30
7	150	149.57	140.93	0.29	6.05
8	150	157.02	133.97	4.68	10.69
9	150	136.17	124.55	9.22	16.97
10	150	141.95	146.49	5.37	2.34
11	150	188.29	162.55	25.53	8.37
12	150	149.79	138.80	0.14	7.47
13	150	160.90	157.13	7.27	4.75
14	150	160.74	139.97	7.16	6.69
15	150	133.15	155.53	11.24	3.69
16	150	152.83	133.84	1.89	10.78
17	150	153.34	139.08	2.23	7.28
18	150	144.17	137.28	3.89	8.48
19	150	149.82	142.05	0.12	5.30
20	150	155.17	146.91	3.45	2.06
21	150	188.29	140.11	25.53	6.60
22	150	149.79	165.71	0.14	10.47
23	150	160.90	140.22	7.27	6.52
24	150	160.74	158.86	7.16	5.90
25	150	133.15	146.95	11.24	2.03
26	150	152.83	156.01	1.89	4.01
27	150	153.34	153.70	2.23	2.47
28	150	144.17	138.44	3.89	7.71
29	150	149.82	145.72	0.12	2.86
30	150	173.67	141.14	15.78	5.91

Table 5.24 showed comparison the waste quantification in terms of weight obtained from ANN and the Q_{CWI} tool. The target weight of construction waste was 200 kg. The Q_{CWI} tool was better than ANN, where the average of error and the deviation standard was smaller than those of the ANN. The average of error was 5.56 (< 8.81) and the deviation standard was 5.52 (< 10.66).

Table 5.24 Comparison the Weight of Waste between ANN and the Q_{CWI} Tool (200 kg)

No	Weight Target (kg)	Results of the ANN	Results of the Q_{CWI} Tool	Percentage Error of the ANN	Percentage Error of the Q_{CWI} Tool
1	200	155.17	166.85	3.45	16.58
2	200	197.42	171.94	1.29	14.03
3	200	211.80	180.79	5.90	9.61
4	200	215.72	174.73	7.86	12.64
5	200	183.81	194.95	8.10	2.53
6	200	223.52	212.02	11.76	6.01
7	200	206.92	171.05	3.46	14.48
8	200	217.93	202.40	8.96	1.20
9	200	226.21	197.23	13.10	1.39
10	200	201.88	167.97	0.94	16.02
11	200	162.21	178.09	18.90	10.96
12	200	195.50	158.36	2.25	20.82
13	200	185.60	184.95	7.20	7.53
14	200	213.05	173.02	6.53	13.49
15	200	230.37	185.75	15.18	7.13
16	200	207.21	168.62	3.61	15.69
17	200	213.28	164.57	6.64	17.72
18	200	209.40	170.85	4.70	14.58
19	200	240.29	168.49	20.15	15.76
20	200	171.22	175.42	14.39	12.29
21	200	177.36	216.05	11.32	8.02
22	200	195.50	211.48	2.25	5.74
23	200	185.60	189.54	7.20	5.23
24	200	213.05	211.50	6.53	5.75
25	200	230.37	186.86	15.18	6.57
26	200	207.21	195.70	3.61	2.15
27	200	213.28	230.71	6.64	15.35
28	200	209.40	216.06	4.70	8.03
29	200	240.29	236.14	20.15	18.07
30	200	171.22	229.09	14.39	11.32

According to Table 5.25, the ANN was better than the Q_{CWI} tool, where the average of the percentage error and the deviation standard were smaller than the Q_{CWI} tool. The average of error was 6.61 (< 19.43) and the deviation standard was 5.19 (< 12.63).

Table 5.25 Comparison the ANN and the Q_{CWI} Tool (in weight, 250 kg)

No	Weight Target (kg)	Results of the ANN	Results of the Q_{CWI} Tool	Percentage Error of the ANN	Percentage Error of the Q_{CWI} Tool
1	250	238.28	212.66	4.69	14.94
2	250	235.15	218.83	5.94	12.47
3	250	211.00	213.09	15.60	14.76
4	250	231.27	256.85	7.49	2.74
5	250	215.31	197.09	13.88	21.17
6	250	238.86	204.30	4.46	18.28
7	250	239.02	229.44	4.39	8.22
8	250	234.94	197.65	6.02	20.94
9	250	237.83	211.49	4.87	15.40
10	250	233.68	206.51	6.53	17.40
11	250	204.63	110.93	18.15	55.63
12	250	217.23	171.35	13.11	31.46
13	250	235.27	165.41	5.89	33.84
14	250	217.98	172.94	12.81	30.83
15	250	216.03	166.53	13.59	33.39
16	250	231.43	168.01	7.43	32.80
17	250	216.08	182.38	13.57	27.05
18	250	235.12	175.55	5.95	29.78
19	250	227.34	170.78	9.07	31.69
20	250	222.84	164.93	10.86	34.03
21	250	251.22	290.59	0.49	16.24
22	250	249.43	282.16	0.23	12.86
23	250	251.27	250.29	0.51	0.12
24	250	255.49	275.00	2.19	10.00
25	250	251.88	247.12	0.75	1.15
26	250	253.62	261.94	1.45	4.78
27	250	252.55	276.44	1.02	10.58
28	250	252.65	241.52	1.06	3.39
29	250	236.44	208.91	5.42	16.44
30	250	247.88	198.79	0.85	20.49

Comparison of volume of construction waste was shown Table 5.26 to Table 5.28. Volume was considered by the density of material waste. Generally, the Q_{CWI}

tool results were better than the ANN. The average of percentage error was about 12.72 (< 18.63) and the deviation standard was 9.76 (< 14.39).

Table 5.22 was the results of construction waste volume based on 150 kg. The Q_{CWI} tool showed better than ANN. The average of error was 7.91 (< 21.27) and the deviation standard value was 4.93 (< 14.98). The Q_{CWI} tool result was more accurate than the ANN result.

Table 5.26 Comparison the Volume of Waste between ANN and the Q_{CWI} Tool (Volume, in m^3, based on 150 kg weight)

No	**Volume Target (m^3)**	**Results of the ANN**	**Results of the Q_{CWI} Tool**	**Percentage Error of the ANN**	**Percentage Error of the Q_{CWI} Tool**
1	0.16	0.22	0.13	37.50	17.10
2	0.16	0.21	0.17	31.25	8.71
3	0.16	0.15	0.14	6.25	14.11
4	0.16	0.16	0.13	0.00	16.25
5	0.16	0.18	0.14	12.50	14.22
6	0.16	0.14	0.13	12.50	20.04
7	0.16	0.17	0.15	6.25	3.32
8	0.16	0.18	0.15	12.50	8.09
9	0.16	0.14	0.14	12.50	14.55
10	0.16	0.16	0.16	0.00	0.50
11	0.21	0.21	0.23	0.00	7.96
12	0.21	0.17	0.19	19.05	7.82
13	0.21	0.16	0.22	23.81	4.35
14	0.21	0.19	0.20	9.52	7.04
15	0.21	0.14	0.22	33.33	3.29
16	0.21	0.17	0.19	19.05	11.11
17	0.21	0.16	0.19	23.81	7.63
18	0.21	0.16	0.19	23.81	8.83
19	0.21	0.18	0.20	14.29	5.66
20	0.21	0.19	0.20	9.52	2.43
21	0.13	0.21	0.12	61.54	6.53
22	0.13	0.17	0.14	30.77	10.55
23	0.13	0.16	0.12	23.08	6.45
24	0.13	0.19	0.14	46.15	5.98
25	0.13	0.14	0.13	7.69	1.96
26	0.13	0.17	0.14	30.77	4.08
27	0.13	0.16	0.13	23.08	2.54
28	0.13	0.16	0.12	23.08	7.64
29	0.13	0.18	0.13	38.46	2.79
30	0.13	0.19	0.12	46.15	5.84

Table 5.27 presented the results of construction waste volume based on weight of 200 kg. The Q_{CWI} tool showed better than ANN. The average of error was 11.14 (< 22.95) and the deviation standard value was 5.96 (< 15.20). The Q_{CWI} tool result was more accurate than the ANN result.

Table 5.27 Comparison the Volume of Waste between ANN and the Q_{CWI} Tool (Volume, in m^3, based on 200 kg weight)

No	**Volume Target (m^3)**	**Results of the ANN**	**Results of the Q_{CWI} Tool**	**Percentage Error of the ANN**	**Percentage Error of the Q_{CWI} Tool**
1	0.22	0.23	0.18	4.55	16.75
2	0.22	0.27	0.19	22.73	14.21
3	0.22	0.25	0.20	13.64	9.79
4	0.22	0.23	0.19	4.55	12.82
5	0.22	0.27	0.21	22.73	2.73
6	0.22	0.25	0.23	13.64	5.79
7	0.22	0.27	0.19	22.73	14.66
8	0.22	0.28	0.22	27.27	0.99
9	0.22	0.23	0.22	4.55	1.59
10	0.22	0.19	0.18	13.64	16.19
11	0.28	0.22	0.25	21.43	11.29
12	0.28	0.19	0.22	32.14	21.12
13	0.28	0.23	0.26	17.86	7.88
14	0.28	0.24	0.24	14.29	13.82
15	0.28	0.25	0.26	10.71	7.48
16	0.28	0.25	0.24	10.71	16.01
17	0.28	0.25	0.23	10.71	18.03
18	0.28	0.28	0.24	0.00	14.90
19	0.28	0.22	0.23	21.43	16.07
20	0.28	0.20	0.24	28.57	12.62
21	0.17	0.22	0.19	29.41	10.22
22	0.17	0.19	0.18	11.76	7.89
23	0.17	0.23	0.16	35.29	3.30
24	0.17	0.24	0.18	41.18	7.90
25	0.17	0.25	0.16	47.06	4.67
26	0.17	0.25	0.17	47.06	0.16
27	0.17	0.25	0.20	47.06	17.70
28	0.17	0.28	0.19	64.71	10.23
29	0.17	0.22	0.20	29.41	20.47
30	0.17	0.20	0.20	17.65	16.88

Table 5.28 presented the results of construction waste volume for 150 kg weight. According to table 5.28, the results were different from Table 5.26 and Table 5.27. The ANN showed better than the Q_{CWI} tool. The average of error and the deviation standard were using as indicators, where those values were smaller than the Q_{CWI} tool. The average of error was 11.67 (< 19.10) and the deviation standard value was 10.17 (< 12.8).

Table 5.28 Comparison the Volume of Waste between ANN and the Q_{CWI} Tool (Volume, in m^3, based on 250 kg weight)

No	Volume Target (m^3)	Results of the ANN	Results of the Q_{CWI} Tool	Percentage Error of the ANN	Percentage Error of the Q_{CWI} Tool
1	0.27	0.28	0.23	3.70	13.54
2	0.27	0.26	0.24	3.70	11.03
3	0.27	0.23	0.23	14.81	13.37
4	0.27	0.25	0.28	7.41	4.42
5	0.27	0.25	0.22	7.41	19.87
6	0.27	0.28	0.22	3.70	16.94
7	0.27	0.27	0.25	0.00	6.72
8	0.27	0.27	0.22	0.00	19.65
9	0.27	0.26	0.23	3.70	14.02
10	0.27	0.26	0.23	3.70	16.04
11	0.35	0.25	0.15	28.57	55.80
12	0.35	0.27	0.24	22.86	31.72
13	0.35	0.28	0.23	20.00	34.09
14	0.35	0.26	0.24	25.71	31.09
15	0.35	0.24	0.23	31.43	33.64
16	0.35	0.26	0.23	25.71	33.05
17	0.35	0.26	0.25	25.71	27.32
18	0.35	0.29	0.24	17.14	30.05
19	0.35	0.27	0.24	22.86	31.95
20	0.35	0.27	0.23	22.86	34.28
21	0.22	0.22	0.25	0.00	14.56
22	0.22	0.20	0.24	9.09	11.23
23	0.22	0.21	0.22	4.55	1.33
24	0.22	0.22	0.24	0.00	8.41
25	0.22	0.21	0.21	4.55	2.58
26	0.22	0.21	0.23	4.55	3.26
27	0.22	0.20	0.24	9.09	8.98
28	0.22	0.22	0.21	0.00	4.79
29	0.22	0.24	0.18	9.09	17.64
30	0.22	0.26	0.17	18.18	21.63

According to the ANN implemented by Qnet-2000, beginning from data input to the result, both the ANN and the Q_{CWI} tool consisted of some advantages and disadvantages. In this research, the number of data for the ANN was limited. The data and three types of construction waste model, bricks, roof tiles and concrete-mortar. Variables of waste model as ANN data were the width of 125 cm with three variables of weight, 150 kg, 200 kg and 250 kg. The total data are ninety. For validation, the base wide of 150 cm with two variables of weight 100 kg and 150 kg were used. In this case, the comparison of both methods was based on two criteria such as easy to use and fast in operation. Table 5.25 showed the comparison between the ANN and the Q_{CWI} tool.

5.7. Conclusions

According to the analysis of the Q_{CWI} tool as explained in section 5.4, the quantification system was possible to use for the real case. Most of the material models showed similar trend for volume and weight measurements. On the other hand, both measurements had a gap or difference result in each of the geometric attribute of volume and weight. The gap increased linearly, from the small size to the big size of waste model. Nevertheless, the regression line and the correlation coefficient were close. This implies that the quantification system was well associated with the model design.

The result of the Q_{CWI} tool showed well associate with the ANN result using the average error and the deviation standard value. The Q_{CWI} tool was better for volume calculation and the ANN was better for weight calculation. According to the comparison, the Q_{CWI} tool can be improved by considering the image scale as default of camera as explained in section 5.5.

Table 5.29 Comparison between the ANN and Q_{CWI} Tool in the Construction Waste Quantification

Variables	**Comparison based on an ease to use criteria**	
	The ANN	The Q_{CWI} Tool
Data Input	• Data input are the numbers of boxes which overlay between gridlines and object of the image. • Level of difficulty of the data input depends on the box size. • Image processing technique is required to disaggregate the object and background. • The numbers of data are classified into training and testing. Validation needs a new set of data.	• Data input are three images from different views. • Quantification of waste is based on the coordinates of the geometric attributes and density value. • Level of difficulty of the data input depends on material characteristic, environment such as illumination, contrast, color of the object. • Pre-processing image technique is required to improve the quality of image. • The numbers of data is fewer.
Process	• A network of input and output is created. • The network needs some parameters to support the relationship between input - output • To find the result, the network needs training-testing-validation session.	• The Q_{CWI} tool is using two types of approaches for waste quantification. There are the ordinary image and the smoothed shape. • The quantification is done by combining two systems in MATLAB and EXCEL.
Output	• The network provides two models in terms of volume and weight. • Level of accuracy depends on size of boxes, the number of data, training and testing session.	• The output of the Q_{CWI} is stored in EXCEL and the coordinate results are controlled in MATLAB. • Level of accuracy of the results depends on the coordinates identification and the density value.
Variables	**Comparison based on operation time**	
Data Input	• Preparing data need a time.	• Preparing data is easier.
Process	• For processing the ANN is faster than the Q_{CWI} tool.	• For processing the prototype tool, it is time consuming.
Output	• Level of accuracy depends on number of data and network parameter.	• Level of accuracy depends on coordinates and density value.

CHAPTER VI
IMPLEMENTATION AND VALIDATION OF THE SYSTEM

This chapter presents a practical discussion concerning to the implementation and validation of the Q_{CWI} tool. This stage is conducted in order to test the reliability of the Q_{CWI} tool to be applied in the real situation. The discussion sets out from the method validation, case study, and the reliability of the Q_{CWI} tool. In the previous chapter, the system had been applied successfully for the construction waste models. The result of the Q_{CWI} tool was capable to quantify the construction waste models in terms of volume and weight. The regression line, the determinant coefficient, and the correlation coefficient were used as the indicator to evaluate the quantification system. The Q_{CWI} tool has a good accuracy for quantification of construction waste comparing the capacity of truck and weight at the weighbridge for volume and weight comparison respectively. This chapter will be divided into four sections 1) the implementation of the Q_{CWI} tool, 2) the validation of the Q_{CWI} tool, 3) the Q_{CWI} tool Operation, and 4) conclusion.

6.1. The Implementation of the Q_{CWI} Tool

The implementation of the quantification system is a method to ensure that the Q_{CWI} tool is acceptable and applicable at the real situation. The use of the Q_{CWI} tool at the construction site is different from employing the tool in the model scale because of two major problems; firstly, the construction site environmental problems such as limited space, various background, inhomogeneous illumination, contrasting and so forth. Secondly, the characteristic of the waste construction such as debris, wood, metal, and etc that piles up in different size as well as shape. Thus, the Q_{CWI} tool should be tested to the real situation to understanding the capability of the tool.

The Q_{CWI} tool supports the construction manager quantifying the construction waste, especially, in measuring the waste production. The data input has three images from different three views. The user determines a boundary of the construction waste stacks, which will be quantified. In general, the application of the Q_{CWI} tool consists of three stages; the data input, the data output and the Q_{CWI} tool operation system.

Figure 6.1 shows the script of the Q_{CWI} tool, which is written under m-file in MATLAB. In the quantification process, the Q_{CWI} tool reads the data input in six times; three times for identifying the object based on the ordinary image, and three times for identifying the object based on the smoothed shape. The results of the Q_{CWI} tool consists of two parts, the first part identifies the coordinates (in pixel unit) and the second part calculates the geometric attributes (width, height) in metric.

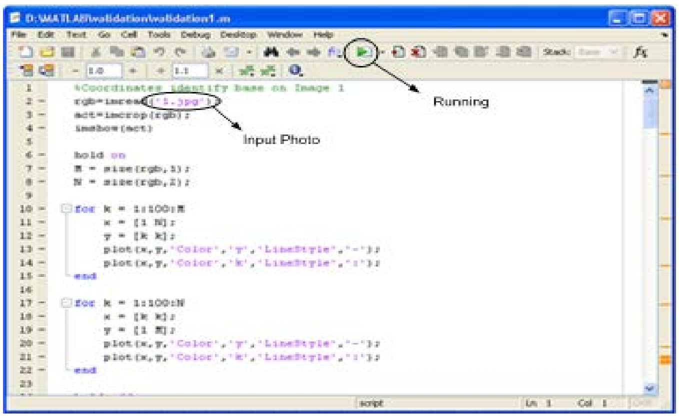


Figure 6.1 User Interface of the Quantification System

Figure 6.2 shows a script for saving the output. The end of the script shows the directory where the data output will be saved. The output is saved in certain directory involving the file name, the sheet name and the row number in the Excel. The Q_{CWI} tool assures that the coordinates cannot be modified. The user can compare the results from MATLAB and Excel.

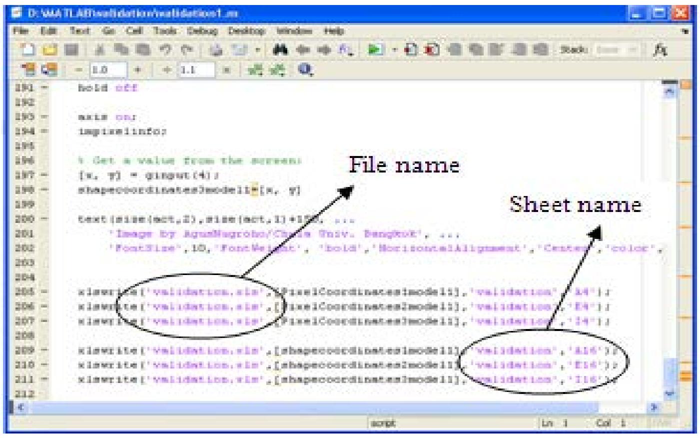


Figure 6.2 The Output of the Q_{CWI} Tool

The user should follow the procedures for the image capture as follows; 1) ensure part of the construction waste will be quantified, 2) identify the boundary of construction waste by marking the outmost of object points, 3) select views for the image capture. These procedures will lead to the three images that represent the whole construction waste.

6.1.1. Camera Calibration

Camera calibration is an important step to the error minimization in geometric attributes measurement. The results of camera calibration are used to determine the object coordinates. Procedures and tool for calibration have been explained in section 4.4.2.1. The results of camera calibration find the intrinsic and extrinsic factors, which give impact to the accuracy of the geometric measurement. Quality of image is influenced by the CCD (charge couple device) of the camera. According to the camera specification, an object in image has a constant composition among width and height of object image which is called the width and height ratio.

6.1.2. Camera Setting and Distance

The distance for image capture is fixed at 2 m from the outmost of the waste stack to the camera position. The determination of the distance refers to the lens specification and the size of the object. The camera lens uses the default of 18 mm – 55 mm which shows the view in the angle range. The angle range is impacted by the focal length. Increasing of the focal length would cause the decreasing of the view of the angle.

6.1.3. Density Test

A value of the material waste density is analyzed based on the density tests, which the density value should be represented the whole characteristics of waste. The density sample is collected from some construction sites in Yogyakarta, Indonesia. Figure 6.3 shows the construction materials left the site as waste and disposed at the landfill. They are the major types of construction waste in Indonesia. Other kinds of waste such as wood, bamboo, steel, paper, wire, and plastic are usually sold to other parties/people which are then used for their own purposes.

Figure 6.3 Types of Construction Waste Disposed at the Landfill

30 samples had been tested in conducting the procedures of density test following the section 4.4.3.2 and the section 5.2.4. The results of weight are shown in Table 6.1 below.

Table 6.1 Weight of 30 Samples

No	Weight (kg)	No	weight (kg)	No	weight (kg)	No	weight (kg)	No	weight (kg)	No	weight (kg)
1	129.5	6	86	11	92.6	16	106.4	21	97.8	26	116.9
2	87.1	7	107.7	12	128.2	17	100.6	22	87.1	27	122.1
3	79.4	8	100.1	13	136.4	18	111.3	23	117.1	28	110.3
4	83.1	9	85.4	14	124.2	19	109.4	24	99.7	29	96.3
5	83.4	10	98.4	15	128.1	20	117.7	25	103.4	30	98.8

The statistic method is used to analyze the density value. The results represent a characteristic of the waste material. This method is supported by class interval and frequency method. Moreover, the data of weight are classified into classes with 10 intervals, and then the frequency of each class is counted based on the emergence of data. The highest frequency in the class interval represents the whole of data samples. Table 6.2 and Figure 6.4 show the result of analysis. The class interval of 95-104 was classified a highest frequency, which the midpoint of the class represents the weight of data samples. Thus, the density value is calculated base on equation 5.1. The density value of the waste was 1,020.20 kg/m^3. The result in the density value calculation was used to calculate the weight of waste in the quantification system.

Table 6.2 Class Interval and Frequency of the Density Test

Class Interval	Frequency
75-84	3
85-94	5
95-104	8
105-114	5
115-124	5
125-134	3
135-144	1

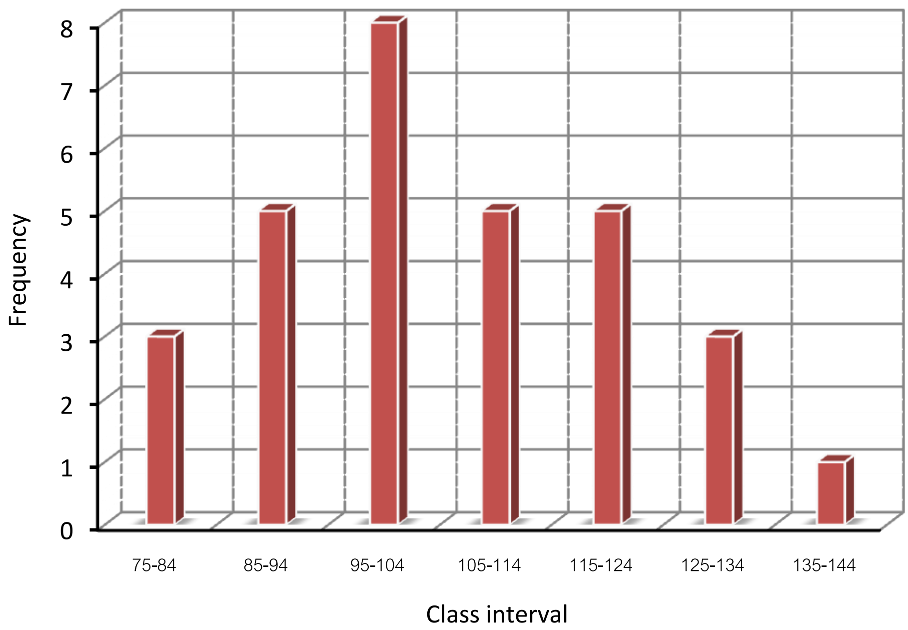


Figure 6.4 Distribution of Frequency of the Density Test

6.2. Validation of the System

In the validation stage, the construction waste was collected from some construction sites by using truck. The numbers of samples for validation are ten data. In terms of volume, this research compares the results of Q_{CWI} tool and the truck capacity. Comparison the waste quantification in terms of weight uses two types of data; weight based on the density value and weight based on the weighbridge weighing. The flow of validation of the Q_{CWI} tool is shown in Figure 6.5 below.

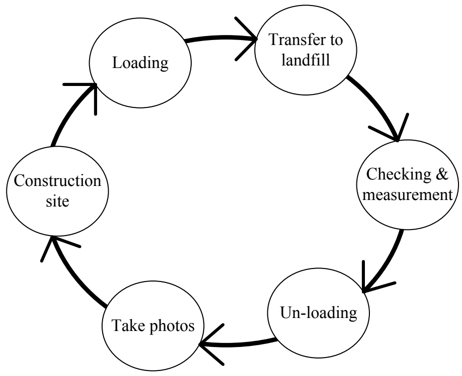


Figure 6.5 A Flow of Validation of the Q_{CWI} Tool

6.2.1 Truck Capacity

The truck capacity is an important factor in order to quantify the construction waste in terms of volume. Capacity of the truck is calculated based on size of the truck's box. This research uses one truck to avoid the deviation in dimension measurements as the comparison. In this research, the box dimension is measured by using the meter tape as shown in Figure 6.6. Full capacity of truck (struck in body) was 5 m^3.

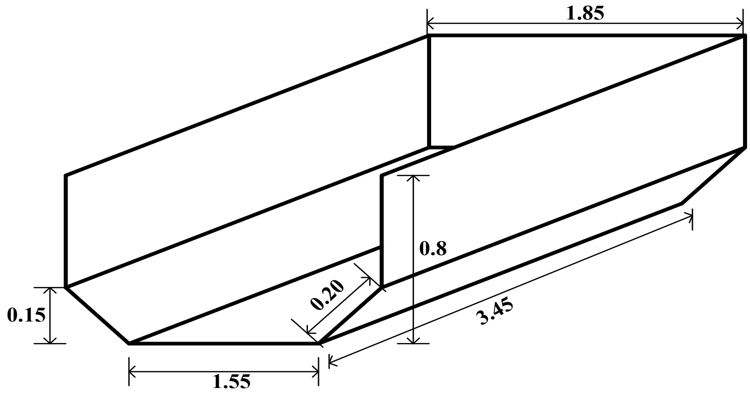


Figure 6.6 Size of the truck's Box

6.2.2 Load of Truck (in terms of volume)

Volume of a load in terms of cubic meter is measured based on the truck capacity. The measurement is done two times, after loading and before unloading. The measurements concern a lot on the load compacting during transportation. Figure 6.7 illustrates volume measurement.

Figure 6.7 Measurement of Load (Truck Number 7)

Table 6.3 shows the results of load measurements. Load of truck is volume of box minus difference of volume between box and load of the truck. According to Figure 6.6, the volume of truck was 5.03 m^3.

Table 6.3 Differences Between Truck Capacity and Load (Truck Number 7)

Right (cm)	Left (cm)	Average (cm)	Right (cm)	Left (cm)	Average (cm)
7.6	10.6	9.1	5.4	7.7	6.55
4.4	9.8	7.1	6.5	12.4	9.45
8.3	11.2	9.75	5.3	4.5	4.9
3.9	11.6	7.75	3.4	4.4	3.9
9.7	7.6	8.65	4.6	9.7	7.15
7.2	5.6	6.4	5	6.8	5.9

Load of the truck is shown in Table 6.4. Truck number two and six were full capacity of truck. The truck capacity as the comparison was in the range of 4.18 m^3 – 5.04 m^3.

Table 6.4 Truck Capacity (in volume. m^3)

No of truck	Volume (m^3)	No of truck	Volume (m^3)
1	4.34	6	5.04
2	5.04	7	4.57
3	4.54	8	4.47
4	4.18	9	4.62
5	4.66	10	4.43

6.2.3 Load of Truck (in terms of weight)

The weight of construction waste from the weighbridge is used as comparison quantity of waste in terms of weight. The weight measurement from the weighbridge is the weight consisting weight of load, the vehicle and operator. Weight of waste can be calculated based on the formula below. The difference of weight between the weighbridge measurement and the Q_{CWI} tool is used to evaluate the accuracy of the quantification system.

Weight of waste = total weight – vehicle weight – operator weight

Figure 6.8 shows the result of the weighbridge measurement. For example, the total weights of the truck number seven and eight were 10,240 kg and 10,300 kg respectively.

Figure 6.8 Measurements of Weight at the Weighbridge

Weight of vehicle can be known from truck certificate, commonly it attach on body of truck. It shows the allowable of truck capacity as shown in Figure 6.9. In Indonesia, the regulation concerning to the load of the vehicle on the highway is the responsibility of the Directorate General of Land Transportation of the Ministry of Transportation.

Figure 6.9 The Certificate of the Allowable Load of a Vehicle

The weight of load as follows.

- Truck number seven

  Weight of load = total weight – vehicle weight – operator weight

  = 10,240 kg – 2,970 kg – 180 kg

  = 7,090 kg

- Truck number eight

  Weight of load = total weight – vehicle weight – operator weight

  = 10,300 kg – 2,970 kg – 180 kg

  = 7,150 kg

Table 6.5 showed the weight of truck load in the range of 4,267 kg – 7,150 kg. Truck number eight showed the largest of load and the truck number four was the smallest of load.

Table 6.5 Load of Truck (in weight, kilograms)

No of truck	Volume (m^3)	Density (Kg/m^3)	Weight (Kg)
1	4.34	1,020.20	4,430.57
2	5.04	1,020.20	5,140.50
3	4.54	1,020.20	4,635.14
4	4.18	1,020.20	4,267.04
5	4.66	1,020.20	4,753.32
6	5.04	1,020.20	5,140.50
7	4.57	1,020.20	7,090.00
8	4.47	1,020.20	7,150.00
9	4.62	1,020.20	4,708.44
10	4.43	1,020.20	4,517.66

6.3. The Q_{CWI} Tool

Implementation and validation were the last part of this research to assure that the Q_{CWI} tool can be applied in real condition. In this stage, the results of the Q_{CWI} tool will indicate that the tool is easy to operation and yet accurate. A set of data had been prepared in order to validate the Q_{CWI} tool. Section 6.1 has explained the camera preparation before image capture and the data were collected in terms of volume based on the capacity of truck and weight based on the weighbridge measurements. Furthermore, the density value was important for identify the weight of construction waste. The sequences of the Q_{CWI} tool work in weight validation process are as follows.

6.3.1 Input Data

The Q_{CWI} tool works under MATLAB software. The user can create a folder to saving the data (image), the script (m-file) and the output under MATLAB directory.

6.3.2 Operation of the Q_{CWI} Tool

In operating the Q_{CWI} tool, the user has an important role to determine the boundary of the waste stack and select the point to find the coordinates. According to the conical shape, each object in image assumed as a triangle shape in two dimensions. The user identifies the geometric attributes through four point coordinates, represented the height and width of the stack waste. Identification of the coordinates is based on two approaches, the ordinary image and the smoothed shape. Figure 6.10 showed the types of construction waste stacks.

Figure 6.10 Types of Construction Waste in the Q_{CWI} Tool Validation

6.3.3 The Output of the Q_{CWI} Tool

The output would be saved in Excel program, automatically. The output was described into two sections 1) the volume output and 2) the weight output. The details of the output of the Q_{CWI} tool will be explained as follows.

6.3.3.1 Volume Output

The results of the Q_{CWI} tool in terms of volume are shown in Table 6.6. The percentage error is used to identify a difference value between both measurements and can be calculated by using the formula below.

$$\text{The percentage error ( )} \quad \frac{\text{olume based on truck} \quad \text{olume based on the} \qquad \text{tool}}{\text{olume based on truck}} \text{ x } 100$$

According to the ordinary image, the differences of volume results were in a range of 0.08 m^3 – 1.08 m^3 and the average 0.59 m^3 or in the range of 1.82 % - 23.55 % (the average was12.95%). The difference of volume results of the smoothed shape were smaller than the ordinary image, which the volume results were in range of 0.14 m^3 – 1.36 m^3 (average was 0.57 m^3) or 2.8 % - 29.12 % (the average was 12.51%). Both approaches in the quantification system showed a good result in the cubic meters or in the percentage error. It was as an indicator that the two approaches were well associated.

Table 6.6 Results of the Q_{CWI} Tool (in terms of volume)

Truck Number	The Q_{CWI} Tool Results in Terms Volume (m^3)		Based on the Truck Capacity (m^3)
	Ordinary Image	Smoothed Shape	
1	4.440	4.56	4.343
2	4.840	5.18	5.039
3	5.358	5.321	4.543
4	5.002	4.573	4.183
5	5.456	6.016	4.659
6	4.561	5.411	5.039
7	5.647	5.179	4.570
8	5.337	5.326	4.466
9	5.278	5.276	4.615
10	4.509	4.758	4.428

Figure 6.11 described the comparison of quantification in terms of volume. The results showed similar value. The details of the comparison between the system and the truck were as follows.

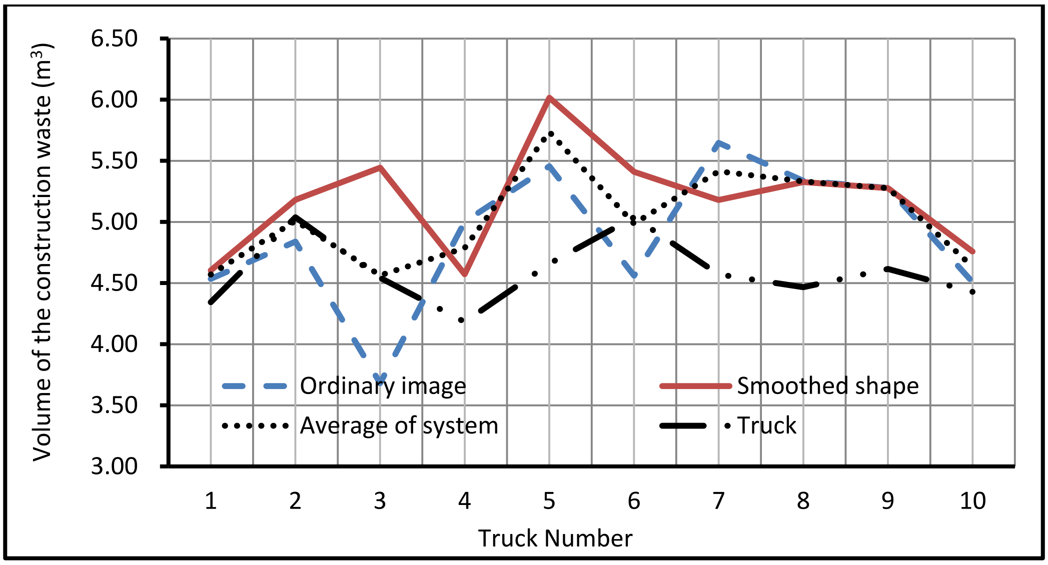


Figure 6.11 Volume of Construction Waste Based on Truck and the Q_{CWI} Tool

Table 6.12 showed the differences of volume measurement in detail. It was a better way to visualize the contrast between the two types of measurements. The differences of the measurement were against to zero lines, which was a simple way to recognize the gap between the Q_{CWI} tool and the truck capacity. The ordinary image was higher than the truck capacity (0.59 m^3); while the smoothed shape tended to be lower than the truck capacity, 0.57 m^3. Truck number ten showed a close gap of 0.08 m^3, and the truck number seven showed the largest gap of 1.08 m^3. Both approaches showed a similar trend. Detail of the differences of measurement was shown in Table 6.7.

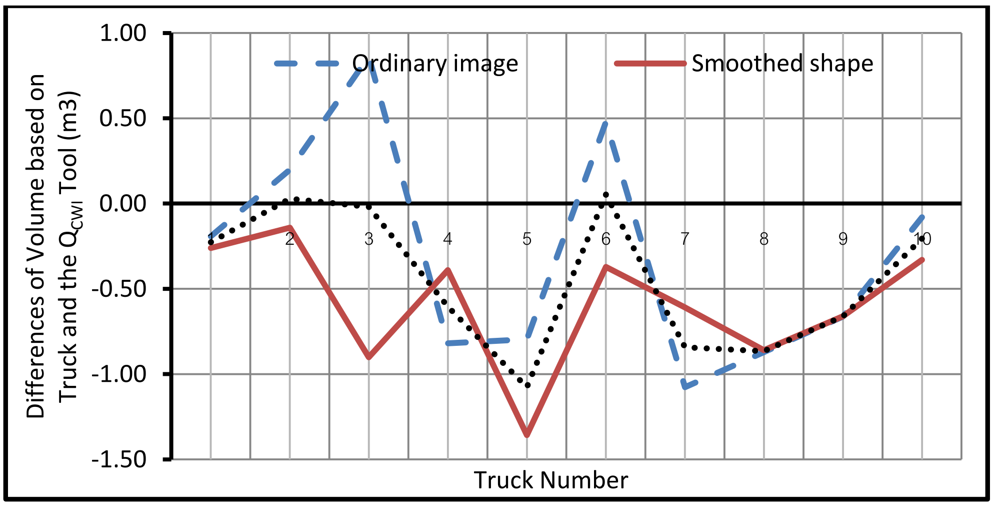


Figure 6.12 Differences of Volume between Truck and the Q_{CWI} Tool

According to Table 6.7, the minus values showed the results from the Q_{CWI} tool were smaller than the truck capacity. All the trucks except truck number two and six, the Q_{CWI} tool results were smaller than the truck capacity. The largest difference was shown by the truck number five, which was difference 1.08 %. According to the results, the quantification system showed a good accuracy.

Table 6.7 Differences of Volume Based on Truck and the Q_{CWI} Tool

Truck Number	Differences of Volume (m^3)		The Q_{CWI} Tool Against Truck capacity (Percentage Error, %)
	Truck (m^3)	Q_{CWI} tool (m^3)	
1	4.343	4.50	-0.16
2	5.039	5.01	0.03
3	4.543	5.34	-0.80
4	4.183	4.79	-0.60
5	4.659	5.74	-1.08
6	5.039	4.99	0.05
7	4.570	5.41	-0.84
8	4.466	5.33	-0.87
9	4.615	5.28	-0.66
10	4.428	4.63	-0.21

Table 6.8 presented the differences of volume measuring, which was a better way to describe the level of accuracy of the Q_{CWI} tool. The difference of volume can be done by comparing column (4) and (9), where the average of volume was greater than the truck capacity. Column (10) and (11) showed the difference of measurement in cubic meter and the percentage error. The Q_{CWI} tool showed the differences of volume measuring between the tool and the truck capacity were in range of 0.03 m^3 – 1.08 m^3. The percentage errors were in range 0.57 % - 23.11 %.

According to the results, the Q_{CWI} tool in both approaches showed a similar value. Truck number two showed the smallest difference and the biggest was shown by the truck number five. Generally, the difference of volume measuring between the Q_{CWI} tool and the truck capacity was 0.53 m^3 or 11.71 %, which could be classified into small disparity.

Table 6.8 Comparison of Construction Waste Volume Based on Truck and the Q_{CWI} Tool

Truck No	Measurement by the Q_{CWI} Tool		Based on Box Truck	Truck VS Ordinary Image		Truck VS Smoothed Shape		Based on the Q_{CWI} Tool	Truck VS the Q_{CWI} Tool	
	Ordinary Image	Smoothed Shape		m3	%	m3	%		m3	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
2	4.84	5.18	5.04	0.2	3.94	0.14	2.8	5.01	0.03	0.57
6	4.561	5.411	5.04	0.48	9.48	0.37	7.39	4.99	0.05	1.05
1	4.44	4.56	4.34	0.1	2.24	0.22	5.00	4.50	0.16	3.62
10	4.509	4.758	4.43	0.08	1.82	0.33	7.45	4.63	0.21	4.64
9	5.278	5.276	4.62	0.66	14.36	0.66	14.32	5.28	0.66	14.34
4	5.002	4.573	4.18	0.82	19.59	0.39	9.34	4.79	0.6	14.46
3	5.358	5.321	4.54	0.81	17.93	0.78	17.12	5.34	0.8	17.52
7	5.647	5.179	4.57	1.08	23.55	0.61	13.31	5.41	0.84	18.43
8	5.337	5.326	4.47	0.87	19.51	0.86	19.26	5.33	0.87	19.39
5	5.456	6.016	4.66	0.8	17.1	1.36	29.12	5.74	1.08	23.11
Av*)	**5.04**	**5.16**	**4.59**	**0.59**	**12.95**	**0.57**	**12.51**	**5.10**	**0.53**	**11.71**

Av*) = average

6.3.3.2 Weight Output

The validation of the Q_{CWI} tool in terms of weight, this research uses two types of comparison. The weight based on the density of the waste material and the weight based on the weighbridge measurements. Details of the differences of weight measurements are explained as follows.

6.3.3.2.1 Weight of Waste Based on the Density Value

Table 6.9 showsed the results of comparison the weights measurements using in the density value and the Q_{CWI} tool. According to the ordinary image results, truck number ten showed the smallest difference and truck number seven was the largest difference compared to the weight based on the density value.

For the smoothed shape results, truck number two was the smallest difference and truck number five was the largest difference. According to the results, both approaches are close to the weight based on the density value.

The ordinary image results were similar to the smoothed shape results. The average value of the ordinary image was 5,139 kg, the smoothed shape was 5,267 kg, and the weight based on the density was 4,699 kg. Generally, the quantification system results were larger than the weight based on the density value.

The differences of weight measuring, for the ordinary image were in a range of 0.72% - 23.11% (the average was 12.38%) or 32 kg – 1,082 kg (the average was 578 kg). The smoothed shape results were in range of 2.81% - 29.13% (the average was 12.13%) or 144 kg – 1,385 kg (the average was 568 kg). According to the results, the smoothed shape was larger disparity than the ordinary image.

Table 6.9 Results of the Q_{CWI} Tool (in terms of weight)

Truck Number	Results of the Q_{CWI} Tool in Terms Weight (kg)		Based on the Density Value
	Ordinary Image	Smoothed Shape	
1	4,530	4,682	4,431
2	4,937	5,285	5,141
3	5,466	5,429	4,635
4	5,102	4,665	4,267
5	5,566	6,138	4,753
6	4,653	5,520	5,141
7	5,761	5,284	4,679
8	5,445	5,433	4,719
9	5,384	5,382	4,708
10	4,550	4,854	4,518

According to the smoothed shape results, the truck number four showed the smallest weight 4,665 kg and truck number two showed a small of the percentage error 2.81%. Truck number five was the largest of the percentage error 29.13 %. Both approaches in the Q_{CWI} tool, the ordinary image and the smoothed shape had similar trend as shown in Figure 6.13 below.

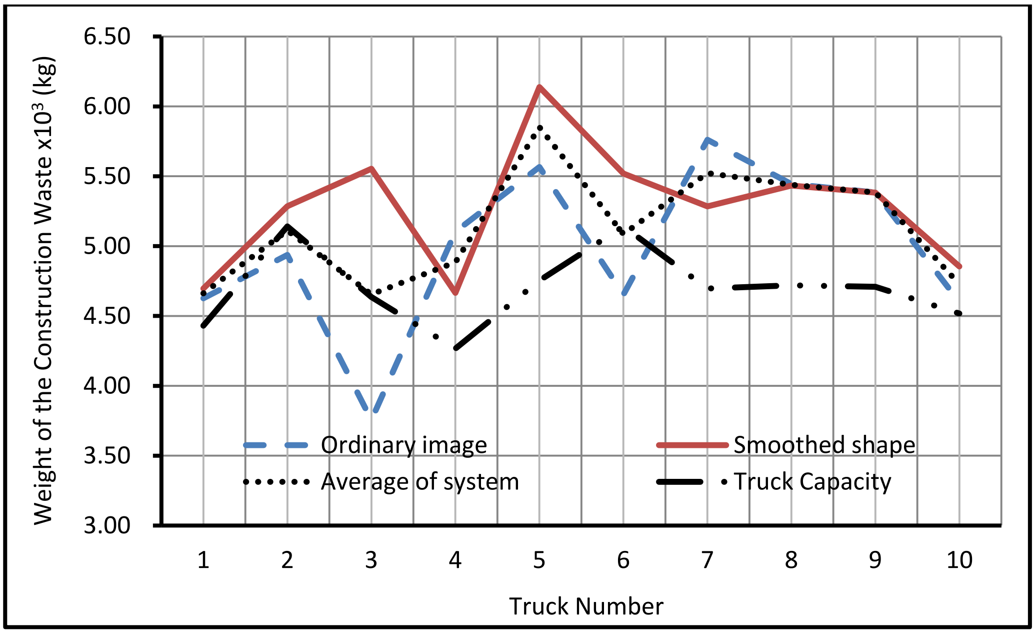


Figure 6.13 Weight of Construction Waste Based on Truck and the Q_{CWI} Tool

Figure 6.14 showed differences of weight measurement based on the Q_{CWI} tool and weight calculation based on the density value. Furthermore, this figure illustrated the difference of weight measurement easily. The result of weight measurement based on the ordinary image was smaller than the weight based on the density value. The truck number ten was the smallest difference by 32 kg and the truck number seven was the greatest difference by 1,082 kg.

According to the smoothed shape, the weight was smaller than the comparator (weight from the weighbridge. The truck number seven was small difference by 144 kg, and truck number five was a large difference by 1,358 kg. Both methods in the Q_{CWI} tool showed the similar trend. Details of the difference of measurement were shown in Table 6.10. The minus of value shows that the result of the system was smaller than the weight based on the density value.

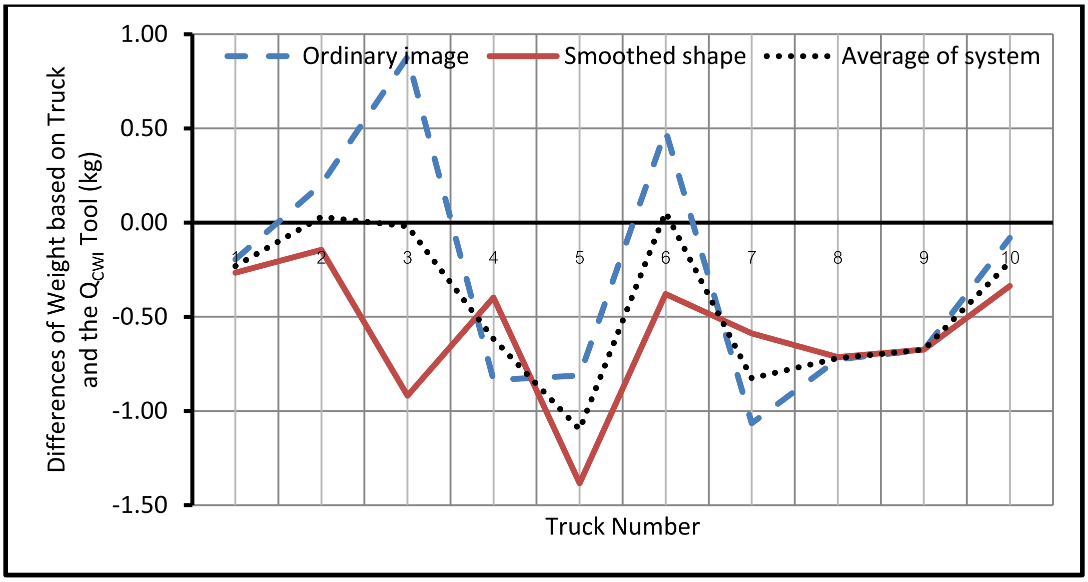


Figure 6.14 Differences of Weight between Truck and the Prototype Tool

According to Table 6.10, the truck number one, three, five, seven, eight and nine showed that the results of quantification were smaller than the truck capacity. Truck number five showed the largest gap by 23.11 % comparing the weight based on the density value.

Table 6.10 Differences of Weight Based on Truck and the Q_{CWI} Tool

Truck Number	Differences of Weight (kg)		Q_{CWI} Tool VS the Density Value (Percentage Error, %)
	Density Value (kg)	Q_{CWI} Tool (kg)	
1	4,431	4,606	3.96
2	5,141	5,111	0.57
3	4,635	5,448	17.53
4	4,267	4,884	14.45
5	4,753	5,852	23.11
6	5,141	5,087	1.05
7	4,696	5,523	18.02
8	4,719	5,439	15.26
9	4,708	5,383	14.33
10	4,518	4,702	4.08

Table 6.11 showed the summary of the measurement in terms of weight. The quantification system showed the difference of measurement was in a range of 30 kg

– 1,099 kg (the average is 521 kg). The percentage errors were in a range 0.57 % - 23.11 % (the average is 11.24 %). The result was classified into small error, which was compared to the weight of truck load (100%).

Table 6.11 Differences of Weight Based on Truck and the Q_{CWI} Tool (Density Value)

Truck No	Measurement by the Q_{CWI} Tool		Based on Box Truck	Truck VS Ordinary Image		Truck VS Smoothed Shape		Based on the Q_{CWI} Tool Results	Truck VS the Q_{CWI} Tool	
	OI*)	SS*)		Kg	%	Kg	%		Kg	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
2	4,937	5,285	5,141	204	3.96	144	2.81	5,111	30	0.57
6	4,653	5,520	5,141	488	9.48	379	7.38	5,087	54	1.05
1	4,530	4,682	4,431	99	2.24	251	5.67	4,606	175	3.96
10	4,550	4,854	4,518	32	0.72	336	7.45	4,702	184	4.08
9	5,384	5,382	4,708	676	14.35	674	14.31	5,383	675	14.33
4	5,102	4,665	4,267	835	19.57	398	9.33	4,884	616	14.45
8	5,445	5,433	4,719	726	15.38	714	15.13	5,439	720	15.26
3	5,466	5,429	4,635	831	17.93	794	17.13	5,448	812	17.53
7	5,761	5,284	4,679	1,082	23.11	605	12.92	5,523	843	18.02
5	5,566	6,138	4,753	813	17.1	1,385	29.13	5,852	1,099	23.11
Av*)	**5,139**	**5,267**	**4,699**	**578**	**12.38**	**568**	**12.13**	**5,203**	**521**	**11.24**

OI*) = Ordinary Image; SS*) =Smoothed Shape; Av*) = Average

6.3.3.2.2 Weight of Waste based on the Weighbridge.

The quantification system results in terms of weight were smaller than the measurement at the weighbridge. Figure 6.15 shows an illustration of the difference of measurement. According to the ordinary image results, the difference of weight between the system and the weighbridge was 1,322 kg. Truck number six showed the largest difference by 2,235 kg and the smallest difference were shown by truck number three 745 kg.

According to the smoothed shape results, the difference of weight was 1,194 kg or the percentage error was 18.29%. Truck number five a relatively little difference by 231 kg and truck number seven showed the greatest difference by 1,806 kg. The smoothed shape result was smaller than the ordinary image.

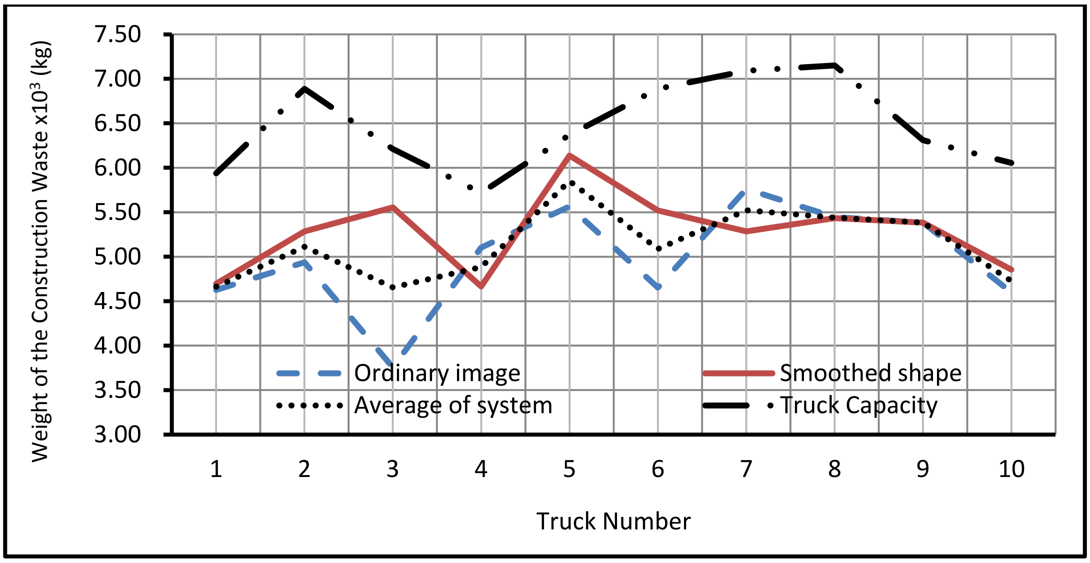


Figure 6.15 Weight Measurement Based on the Weighbridge

Figure 6.16 showed the difference of weight based on the ordinary image and the weighbridge measurement. It was 19.24 %. The result of smoothed shape was larger than the ordinary image of weight difference by 20.20 %.

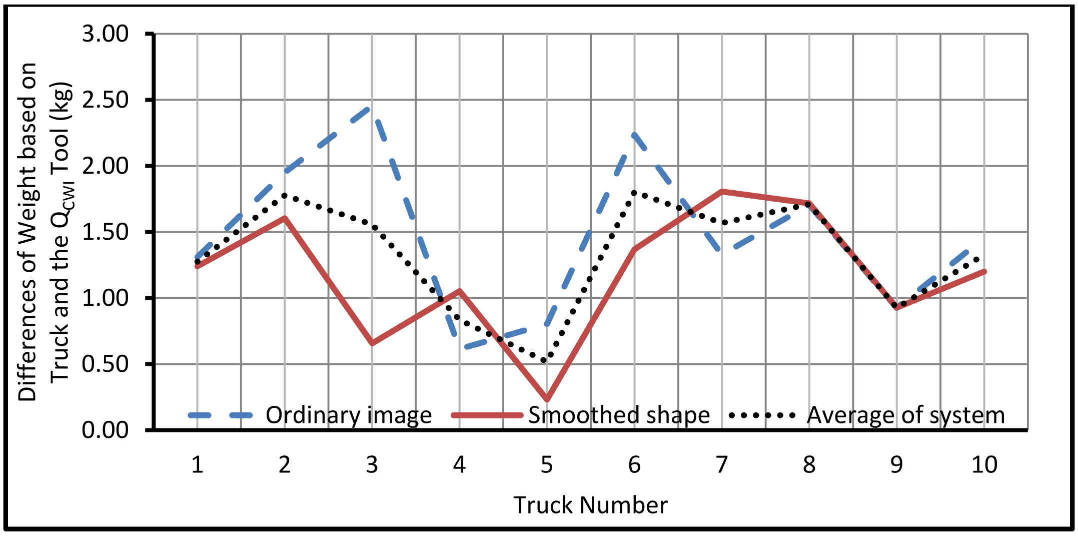


Figure 6.16 Differences of Weight Measurement Based on the Weighbridge

Table 6.12 showed the difference of weight based on the Q_{CWI} tool and the weighbridge measurement. The weight measurements of the system were in range of 4,606 kg – 5,852 kg (the average is 5,230 Kg). And comparing with the weighbridge, the difference was in range of 517 kg – 1,777 kg (the average was 1,258 Kg). The percentage error was in range of 8.12 % - 25.80 % (the average was 19.24 %).

Table 6.12 Differences of Weight Based on the Q_{CWI} Tool and the Weighbridge

Truck No	Measurement by the Q_{CWI} Tool		Based on Box Truck	Truck VS Ordinary Image		Truck VS Smoothed Shape		Based on the Q_{CWI} Tool Results	Truck VS the Q_{CWI} Tool	
	Ordinary Image	Smoothed Shape		Kg	%	Kg	%		Kg	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
5	5,566	6,138	6,369	803	12.61	231	3.63	5,852	517	8.12
3	5,466	5,429	6,211	745	12	782	12.59	5,448	764	12.29
4	5,102	4,665	5,718	616	10.77	1,053	18.41	4,884	834	14.59
9	5,384	5,382	6,309	925	14.67	927	14.7	5,383	926	14.68
7	5,761	5,284	7,090	1,329	18.74	1,806	25.47	5,523	1,568	22.11
10	4,550	4,854	6,054	1,504	24.84	1,200	19.82	4,702	1,352	22.33
1	4,530	4,682	5,937	1,407	23.7	1,255	21.14	4,606	1,331	22.42
8	5,445	5,433	7,150	1,705	23.85	1,717	24.01	5,439	1,711	23.93
2	4,937	5,285	6,888	1,951	28.33	1,603	23.28	5,111	1,777	25.8
6	4,653	5,520	6,888	2,235	32.45	1,368	19.86	5,087	1,802	26.16
Av	**5,139**	**5,267**	**6,461**	**1,322**	**20.20**	**1,194**	**18.29**	**5,203**	**1,258**	**19.24**

Av*) = Average

6.4. Analysis Using the 95 % Limit of Agreement Method

The 95% Limit of Agreement is one of the methods to compare a difference or a gap between two types of measurements (Bland and Altman, 1986). This method is to ease estimate and interpret for the measurement on the same subject. This method has been used to evaluate the interchangeability of blood pressure measurements between a new type of electronic instrument and the commonplace sphygmomanometer (an old instrument with the mercury bar). In this research, we intended to evaluate the discrepancy of quantification of construction waste between the Q_{CWI} tool and the measurement based on the truck capacity, in terms of volume (in cubic meters) and weight (in kilograms). The analysis of the results was carried out in two types of units, the analysis of the volume result and the analysis of the weight result as follows.

The 95% Limit of Agreement method is based on two assumptions: (1) the mean and standard deviation of the difference between the two sets remain constant along the entire range of measurements, and (2) the differences between the two sets roughly follow a normal distribution (Bland and Altman, 1986). The data are described into the diagram x, y which represent two types of measurements. Two type graphs for data illustration are the scattered plot and histogram.

In analyzing using this method, the mean and the deviation standard from the data were used to justify the result. The result is considered acceptable, if it is in range of the upper and the lower limit. The limitation can be calculated based on the equation below.

$$Lower\ limit = \bar{x} - 1.96\ sd \qquad (6.1)$$

$$Upper\ limit = \bar{x} + 1.96\ \mathrm{sd} \qquad (6.2)$$

Where, the mean difference is $\bar{x}$ and sd is the standard deviation of the differences measurement.

6.4.1 Analysis of the Volume Results

The result of construction waste quantification in terms of volume is shown in Table 6.13 below. The differences of volume measurement were the volume based on truck capacity minus the volume based on the Q_{CWI} tool, which consisting of the ordinary image, the smoothed shape, and the average of both approaches.

Table 6.13 The Differences of Construction Waste Volume (in, m^3)

Measurement Based	1	2	3	4	5	6	7	8	9	10
Ordinary Image, m^3	-0.09	0.20	-0.82	-0.82	-0.80	0.48	-1.08	-0.67	-0.67	-0.08
Smoothed Approach, m^3	-0.25	-0.14	-0.78	-0.39	-1.36	-0.37	-0.61	-0.66	-0.66	-0.33
Average, m^3	-0.18	0.03	-0.80	-0.61	-1.08	0.05	-0.84	-0.66	-0.66	-0.20

The normal distribution diagram as a requirement to use the 95% method is shown in Figure 6.17 below

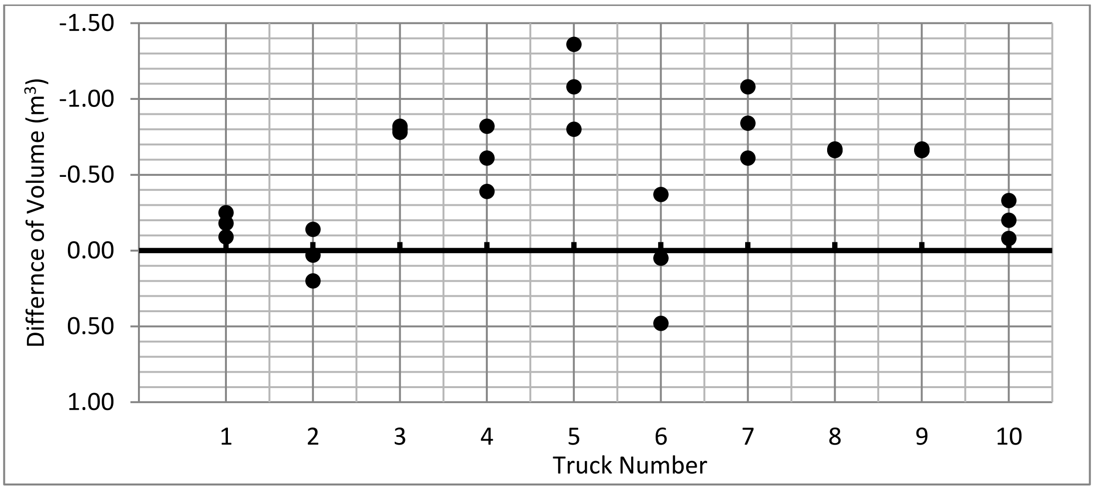


Figure 6.17 Distributions of the Differences of Volume between Both Measurements

The results of the Q_{CWI} tool can be accepted, if the results are in a range of the lower and the upper data. According to Table 6.13, the mean was – 1.08 and the standard deviation as 0.39. By using equation 6.1 and 6.2, the lower limit was -1.85 and the upper limit was -0.31. The illustration of the 95% confidence interval was shown in Figure 6.18 below.

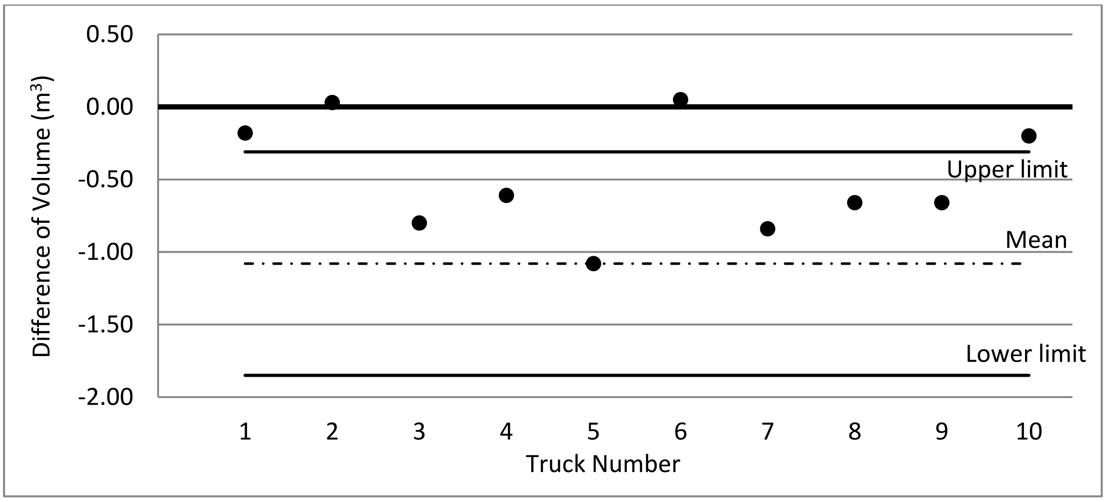


Figure 6.18 The 95% Confidence Intervals for the Differences of Volume

Figure 6.18 shows 60% of the results were in the range of the lower and the upper limit.

6.4.2 Analysis of the Weight Based on the Density Value

The results of the construction waste quantification in terms of weight are shown in Table 6.14 below. The differences of the measurement were the weight based on the density value minus the weight based on the Q_{CWI} tool which consists of the ordinary image, the smoothed shape, and the average of both measurements.

Table 6.14 The Difference of Construction Waste Weight (in, kg) based on the Density Value

Measurement Based	1	2	3	4	5	6	7	8	9	10
Ordinary Image, kg	-0.09	0.80	-0.22	0.68	-0.31	0.18	-1.08	-0.41	0.26	0.62
Smoothed Approach, kg	-0.29	-0.01	-0.61	-0.20	-0.86	-0.15	-0.61	-0.74	-0.60	0.33
Average, kg	-0.19	0.39	-0.41	0.24	-0.58	0.02	-0.84	-0.58	-0.17	0.48

Based on the method assumption, the data should be represent the normal distribution diagram as shown in Figure 6.19 below

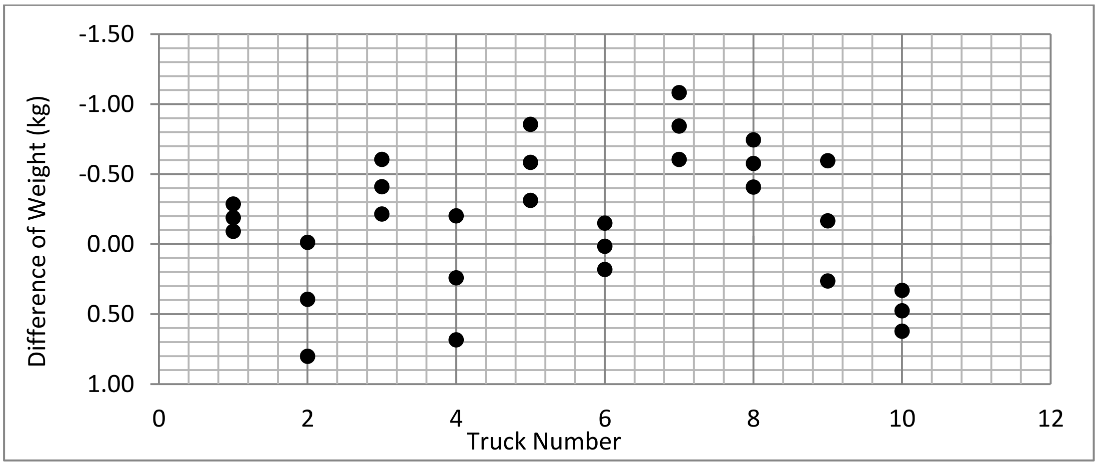


Figure 6.19 Distributions of the Differences of Weight Using the Q_{CWI} Tool Measurements

To obtain the confidence level of the Q_{CWI} tool, the results should be in a range of the lower and the upper data. According to Table 6.14, the mean and the standard deviation were – 0.84 and 0.45 respectively. By using equation 6.1 and 6.2, the lower limit was -1.72 and the upper limit was 0.03. All data in terms of weight are multiplied by 10^3. The illustration of the 95% confidence level was shown in Figure 6.18 below.

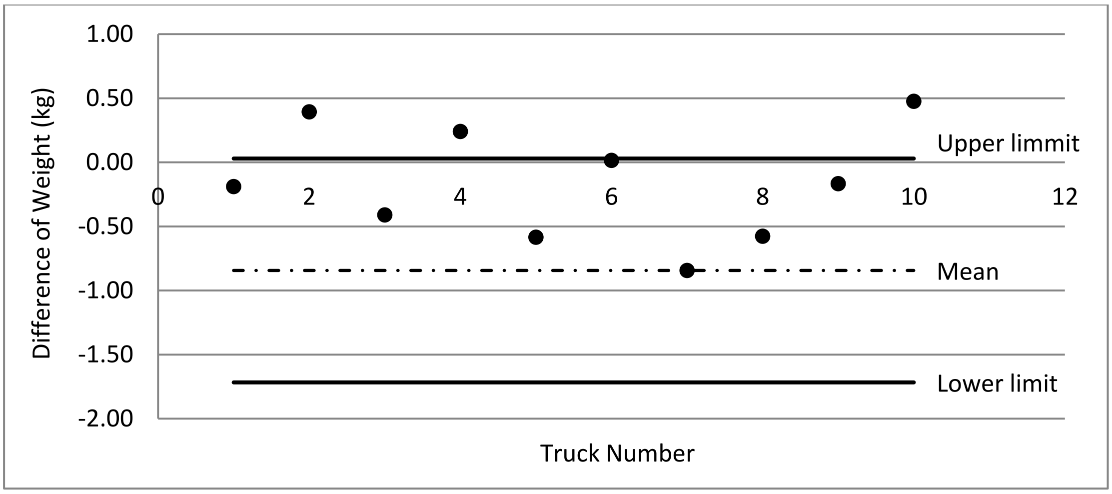


Figure 6.20 The 95% Confidence Intervals for the Differences of Weight based on the Density Value

Figure 6.20 shows that 70% of the results were in the range of the lower and the upper limit.

6.4.3 Analysis of the Weight Based on the Weighbridge Measurement

The result of construction waste quantification in terms of weight was shown in Table 6.15 below. The weight differences of the measurement was the weight based on the weigh bridge measurement minus the weight based on the Q_{CWI} tool which consisting of the ordinary image, the smoothed shape, and the average of both measurements.

Table 6.15 The Differences of Construction Waste Weight (in, kg) based on the Weighbridge

Measurement Based	1	2	3	4	5	6	7	8	9	10
Ordinary Image	1.41	2.55	1.36	2.13	1.30	1.93	1.33	2.02	1.86	2.16
Smoothed Approach	1.22	1.73	0.97	1.25	0.76	1.60	1.81	1.69	1.00	1.87
Average	1.32	2.14	1.17	1.69	1.03	1.76	1.57	1.85	1.43	2.01

To analysis using the 95% limit of agreement method, the data of weight measurement should represent the normal distribution diagram as shown in Figure 6.21 below.

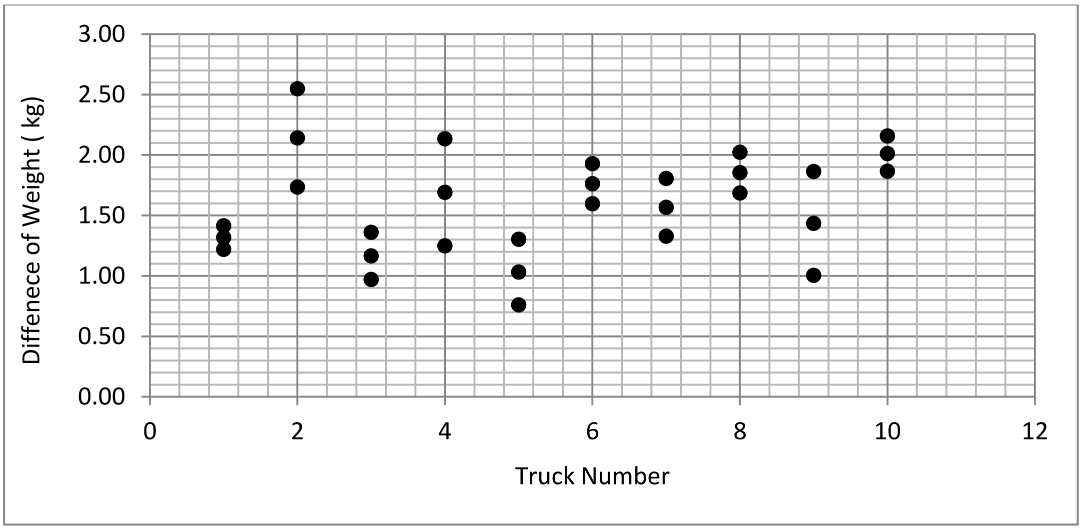


Figure 6.21 Distributions of the Differences of Weight Using the Q_{CWI} Tool Measurements

To obtain the confidence level, the results of the Q_{CWI} tool should be in a range between the lower and the upper data. According to Table 6.15, we can find that the mean was 1.03 and the standard deviation was 0.36. By using equation 6.1 and 6.2, the lower limit was 0.32, and the upper limit was 1.74. All data in terms of weight was multiplied by 10^3. The illustration of the 95% confidence interval was shown in Figure 6.22 below.

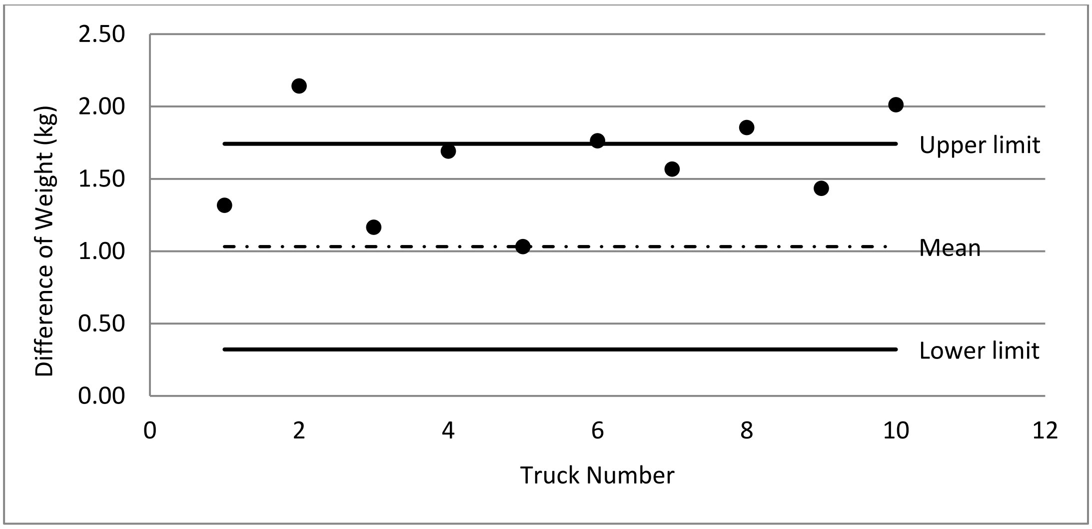


Figure 6.22 The 95% Confidence Intervals for the Differences of Weight based on the Weighbridge

According to the weighbridge measurement, the comparison the quantity of waste in term of weight was shown in Figure 6.22. 70% of the results were in the range between the lower and the upper limit.

6.5. Testing the Q_{CWI} Tool by Users

Since the Q_{CWI} tool is also tested for other users, their information related to the capability of the Q_{CWI} tool can be used to support the improvement of the system as well as the understanding on handling and using the tool among users. This stage is carried out in three steps following:

6.5.1. Introduction of the Q_{CWI} Tool

The researcher introduces the Q_{CWI} tool to the other users, including the parts of the Q_{CWI} tool, the function and the Q_{CWI} tool operations. Furthermore, the researcher introduces details related to data input, process and analysis the output.

6.5.2. Operation of the Q_{CWI} Tool

The researcher trains to the other users how to operate the Q_{CWI} tool. The detail of the Q_{CWI} tool is a part of the concern in training, besides the identification of coordinates based on two types of approaches. Especially, for the smoothed shape approach, the researcher should explain part of this approach such as the smooth line, adjusted shape and the framework for this approach. Furthermore, the training also includes analysis the output of the system. Improving the Q_{CWI} tool includes improving the level of accuracy of the result and avoiding data manipulation related to the volume and weight of construction waste.

6.5.3. Results of the Q_{CWI} Tool

In this stage, the researcher invites five users to test the Q_{CWI} tool. In case, the other users quantify the construction waste using the same images. Each user operated the Q_{CWI} tool through three times training to get well understanding of the tool. The best result was found after three times of operating the system. Detail of other users result was shown in table 6.16 below.

Table 6.16 Results of the Q_{CWI} Tool Testing

Data Source	Author	User 1	User 2	User 3	User 4	User 5
Image 1						
Volume (m^3)	5.43	4.08	4.12	3.5	3.28	3.86
Weight ($kg * 10^6$)	5.54	4.16	4.19	3.59	3.35	3.93
Image 2						
Volume (m^3)	5.34	6.1	5.75	5.49	5.42	5.66
Weight ($kg * 10^6$)	5.45	6.22	5.86	5.61	5.53	5.78
Image 3						
Volume (m^3)	4.99	5.8	5.9	5.42	5.41	5.75
Weight ($kg * 10^6$)	5.09	5.96	6.04	5.23	5.52	5.87

Table 6.17 showed the differences of the results between the experiment and the other users. According to Table 6.17, the maximum difference was 1.35 m^3 and the minimum difference was about 0.01 m^3 in volume measurement. Mean of the volume results was -0.81 and the deviation standard was about 0.56.

For weight measurement, the maximum difference was 1.38 kg, and the minimum was about – 0.25 kg. The mean of the volume results was -0.87 and the deviation standard was about 0.60. According to both results, it was proven that the Q_{CWI} tool can be applied for the other users.

Table 6.17 The Difference of Results from the Experiments and the Other Users

Data Source	Author	User 1	User 2	User 3	User 4	User 5
Image 1						
Volume (m^3)	0	1.35	-0.04	0.62	0.22	-0.58
Weight ($kg * 10^6$)	0	1.38	-0.03	0.6	0.24	-0.58
Image 2						
Volume (m^3)	0	-0.76	0.35	0.26	0.07	-0.24
Weight ($kg * 10^6$)	0	-0.77	0.36	0.25	0.08	-0.25
Image 3						
Volume (m^3)	0	-0.81	-0.1	0.48	0.01	-0.34
Weight ($kg * 10^6$)	0	-0.87	-0.08	0.81	-0.29	-0.35

6.6. Conclusion

The results of the Q_{CWI} tool in terms of volume and weight showed that the system can be successfully implemented in the real condition for construction waste quantification. Especially, the accuracy of the Q_{CWI} tool in terms of measuring volume and weight were a good result. However, in terms of weight, the system needed some improvements to overcome limitations related to the density value of the construction waste materials.

Apart from the deviation about of the Q_{CWI} tool in terms of volume and weight, the Q_{CWI} tool can be used in real practice. The construction manager can manage and quantify the waste production properly. Furthermore, according to the Q_{CWI} tool testing it proved to be applied by the other users.

CHAPTER VII
CONCLUSIONS AND RECOMMENDATION

This chapter presents the summary of the research and explains into six sections: 1) conclusions of the research, 2) benefits of the research, 3) outcomes of the research, 4) contributions of the research, 5) recommendation and limitations, 6) future research.

7.1. Research Conclusions

The research was initiated from the awareness about the existence of the current problems concerning the construction of waste quantification. Currently, the most construction managers think that pay attention to construction waste is associated to the cost. The construction waste is not their priority in a construction process. They prefer to concern on the project objectives (such as time, quality cost and safety), which cause the construction waste to be neglected and trigger a serious problem in the future. Indeed, the most construction managers pay less attention to the construction waste that contributes to the environmental disruption. They only focus on waste disposal of the construction site without any information related to waste quantity. The Q_{CWI} tool system was designed to support them in order to quantify the waste properly, especially the waste production.

The Q_{CWI} tool system is designed based on a simple concept and affordable in cost, therefore it is hoped that the project managers will be interested in using the tool. It is an easy tool to operate yet accurate. The choice of tools and technology is based on the current technology and the cost. A camera is used to provide image data, MATLAB is applied to analyze the data, and EXCEL is used to develop the system and data storage. The process of the Q_{CWI} tool in order to waste quantification is designed as follows:

First, a pilot research was carried out by identifying a shape of the construction waste stack. The shape of the waste stack is adopted from the real condition in the construction site. Then the adopted shape is used to capture the real shape of construction waste stack. The shape of the construction waste was close to a conical shape. In this stage, trial and error of the camera setting was also made, including the focal length, the angle of shooting, the distance between camera and object. The Q_{CWI} tool operation consists of three stages: data acquisition, data transfer and data analysis. Data acquisition was done by using tools, equipments and procedures of image capture. Data were transferred using a micro disk from the camera to the computer. Data analysis is processing data to get the results of the systems. Data analysis involves three steps: 1) image pre-processing (optional), 2) the quantification system approach, and 3) the output. Image pre-processing is a process to reduce a noise, disaggregate between the object and background and removing unnecessary background in image. The objective of this stage supports the user to identifying the object. Some techniques used to enhancement the image such as contrasting, brightness, and darkness. The Q_{CWI} tool provides two types approaches; the ordinary image and the smoothed shape. Furthermore, this stage provides a process to identify the coordinates to find the attribute of the conical. The smoothed shape is a method to make up the waste stack in image graphically (smoothed line). The results of the system were referred to an average value from both approaches.

Second, the testing of the Q_{CWI} tool is planned to identify the problems of the system. The testing uses a construction waste model, which uses the almost homogeneous materials. The materials testing are bricks, roof tiles and concrete-mortar. The density test was also done to support the quantification in terms of weight. Material wastes were classified into four classes 1) large-size, more than 10 cm, 2) medium-size, 5 – 9 cm, 3) small-size, less than 5 cm, and 4) mix-size materials.

The last, the validation system was done to ensure that the Q_{CWI} tool can be applied in the real situation. Capacity of truck was used as comparator to validate the system results. The Q_{CWI} tool is used to quantify the construction waste in terms of volume (in cubic meters) and weight (in kilograms/tons). To validate the quantification of waste in terms of weight, the research uses two types of weight comparisons, 1) the weight based on the density value and 2) the weight from the weighbridge. The results of the system were obtained from 10 times of trucks.

The results of the Q_{CWI} tool were differentiated into two units of quantifications, 1) in terms of volume and 2) in terms of weight. In terms of volume, in cubic meters, the Q_{CWI} tool shows a good result with the percentage error was 11.71% or 0.53 m^3. These results indicate that the prototype tool can be successful to be applied at the real construction waste. In terms of weight, the result of the system shows the percentage error was 11.24 % or 521 kg compared to the weight that had been calculated based on the density value. The percentage error regarding the weight measurement based on the weighbridge was 19.24% or 1,258 kg.

According to the result, the research has demonstrated that the Q_{CWI} tool research can be implemented in the real construction. The shape of construction waste stack is an important factor in the implementation of the Q_{CWI} tool. Therefore, the construction managers should give a direction to workers to manage the construction waste by disposing waste properly. The research is limited to quantification of waste in terms of weight, while the quantity of waste depends on the density value.

7.2. Research Benefits

According to research process and the results, the Q_{CWI} tool is as an alternative tool by the construction managers to quantify the construction waste production, especially, in applying waste quantification in the multi storey construction. The advantages of the Q_{CWI} tool are as follows:

7.2. 1 Easy to use.

The Q_{CWI} tool is designed for easy to be applied. Process of the system is including data input, operation and output. Most of the construction project staff or personnel of the construction field can operate the Q_{CWI} tool.

7.2. 2 Fast in operation.

Operation of the Q_{CWI} tool is faster than current methods. The Q_{CWI} tool quantifies the waste based on three images. It does not require the data from the previous project neither does it require to record the data. The image provides information to waste quantification.

7.2. 3 Acceptable in accuracy.

According to the results analysis, the accuracy of the Q_{CWI} tool is in range of acceptable area. It is proven by the results of the 95% limit of agreement method. The results of the QCWI tool are 60 % - 70 % in range of the lower and the upper limit.

7.2. 4 Affordable in cost.

The component of the Q_{CWI} tool consists of data, technique and tools are more economical than the current technology, for example, the 3D scanner. According to the cost production, The Q_{CWI} tool is cheaper than the 3D scanner.

7.3. Research Outcomes

Research outcomes are as follows:

7.3.1 The use of camera and digital image as data source for waste quantification is a new conceptual framework, especially to measure the waste production in waste management.

7.3.2 There are two types of the proposed approaches in the Q_{CWI} tool; they are new approach in order to quantification of construction waste. The two approaches are the ordinary image and the smoothed shape.

7.3.3 The Q_{CWI} tool produces the quantification of construction waste in two terms quantities: volume in cubic meters and weight in kilograms.

7.4. Research Contributions

In developing countries, the construction waste is not a priority in the construction site system. Therefore, the management of construction waste is not applied properly. The Q_{CWI} provides an alternative tool for quantification of construction waste. It can support the construction managers to measure the quantity of construction waste. The waste production can be measured daily, weekly, monthly and also total amount of construction waste as the information for environmentalists to manage the landfill capacity.

7.5. Limitation and Recommendation

In this research, type of construction waste is limited for these solid waste. In fact, there are many types of construction wastes. Thus, the Q_{CWI} tool can be developed for the other kinds of waste such as ceiling waste, steel waste, wood waste and others, which may exist during the construction process.

The Q_{CWI} tool needs to be improved, by using an automatic system for data transfer to the computer directly using current technology such as Wireless, LRFID, and so fort to reduce time consumption for data transfer.

Based on these research results, the density value is an important factor in the quantification of construction waste in terms of weight. For the future research, the density of construction waste should be increased including type of materials waste, number of samples, the other variables to represent the density in the real condition.

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APPENDIX A

A1. Density Value of Brick Waste

A2. Density Value of Roof Tile Waste

A3. Density of Value of Concrete Mortar Waste

Appendix A1. Density Value of Bricks Waste

Table A1. Density Test for Bricks Waste

	Weight of Bricks Debris (kg)			
	Large Size >10 cm	**Medium Size 5 – 9 cm**	**Small Size < 5 cm**	**Mixed Size**
	73.4	82.3	91.4	85.6
	76.0	83.2	91.2	88.4
	74.6	82.2	91.6	87.9
	71.9	84.6	92.1	89.9
	74.6	83.6	93.2	90.0
	76.9	84.8	93.6	88.4
	74.0	85.9	92.3	87.5
	74.4	86.3	94.7	89.7
	75.3	83.9	93.5	91.0
	74.4	84.2	95.3	90.1
Average	74.55	84.1	92.89	88.85
	Volume (m^3)			
	97.53			
Density	0.76438	0.862299	0.952425	0.911002

Appendix A2. Density Value of Roof Tile Waste

Table A2. Density Test for Roof Tile Waste

	Weight of Roof Tile Debris (kg)			
	Large Size >10 cm	**Medium Size 5 – 9 cm**	**Small Size < 5 cm**	**Mixed Size**
	54.3	67.7	73.1	66.3
	56.5	68.1	73.7	69.2
	57.1	68.6	74.7	67.6
	58.4	70.4	75.4	69.5
	57.0	69.3	74.7	70.2
	56.7	71.6	74.9	71.0
	56.1	72.0	76.7	70.6
	60.0	72.7	76.0	71.0
	58.0	72.0	78.2	71.8
	58.9	73.4	77.5	72.4
Average	57.3	70.58	75.49	69.96
	Volume (m^3)			
	97.53			
Density	0.587512	0.723675	0.774018	0.717318

Appendix A3. Density of Value of Concrete Mortar Waste

Table A3 Density Test for Concrete Mortar Waste

	Weight of Concrete Mortar Debris (kg)			
	Large Size >10 cm	**Medium Size 5 – 9 cm**	**Small Size < 5 cm**	**Mixed Size**
	102.9	105.2	105.0	112.1
	102.1	108.0	109.8	113.6
	103.7	107.3	110.6	109.8
	105.2	108.7	109.9	110.3
	102.7	109.1	110.5	114.4
	102.9	109.6	111.8	112.3
	104.5	111.7	112.8	114.5
	105.5	112.2	112.6	112.9
	106.8	111.6	111.1	112.7
	106.4	114.7	110.8	111.7
Average	104.3	109.8	110.5	112.4
	Volume (m^3)			
	97.53			
Density	1.069107	1.12591	1.132882	1.152774

APPENDIX B

B1. Results of the Brick Waste Model

B2. Results of the Roof Tile Waste Model

B3. Results of the Concrete Mortar Waste Model

Appendix B1. Results of the Brick Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Brick 150 kg(weight) - 100 cm (width)	1	100	42.300	102.122	44.290	105.004	44.773	-2.122	-1.990	-5.004	-2.473	-2.122	-4.706	-5.004	-5.846
	2	100	40.000	101.219	42.033	104.254	41.433	-1.219	-2.033	-4.254	-1.433	-1.219	-5.083	-4.254	-3.583
	3	100	43.300	96.026	43.674	100.330	41.910	3.974	-0.374	-0.330	1.390	3.974	-0.863	-0.330	3.210
	4	100	40.500	94.909	42.127	101.155	41.492	5.091	-1.627	-1.155	-0.992	5.091	-4.017	-1.155	-2.449
	5	100	40.200	98.578	40.257	104.082	39.904	1.422	-0.057	-4.082	0.296	1.422	-0.141	-4.082	0.736
	6	100	41.700	93.190	41.708	98.200	42.025	6.810	-0.008	1.800	-0.325	6.810	-0.019	1.800	-0.780
	7	100	47.500	96.566	48.477	100.165	47.454	3.434	-0.977	-0.165	0.046	3.434	-2.056	-0.165	0.097
	8	100	43.800	99.540	43.330	103.174	42.554	0.460	0.470	-3.174	1.246	0.460	1.072	-3.174	2.845
	9	100	43.400	94.611	44.747	99.728	42.206	5.389	-1.347	0.272	1.194	5.389	-3.104	0.272	2.751
	10	100	45.700	98.398	45.246	103.056	44.117	-3.056	0.454	-3.056	1.583	-3.056	0.993	-3.056	3.465
Average								**2.018**	**-0.749**	**-1.915**	**0.053**	**2.018**	**-1.793**	**-1.915**	**0.045**

Brick 150 kg(weight) - 125 cm (width)	1	125	38.000	101.634	38.667	107.600	34.243	23.366	-0.667	17.400	3.757	18.693	-1.755	13.920	9.888
	2	125	43.400	103.468	43.520	115.402	43.378	21.532	-0.120	9.598	0.022	17.225	-0.277	7.679	0.050
	3	125	40.000	96.026	43.674	100.330	41.910	28.974	-3.674	24.670	-1.910	23.179	-9.185	19.736	-4.775
	4	125	42.000	94.909	42.127	101.155	41.492	30.091	-0.127	23.845	0.508	24.073	-0.302	19.076	1.210
	5	125	37.800	98.578	40.257	104.082	39.904	26.422	-2.457	20.918	-2.104	21.138	-6.499	16.734	-5.566
	6	125	44.100	93.190	41.708	98.200	42.025	31.810	2.392	26.800	2.075	25.448	5.424	21.440	4.704
	7	125	40.400	96.566	48.477	100.165	47.454	28.434	-8.077	24.835	-7.054	22.748	-19.992	19.868	-17.460
	8	125	41.900	99.540	43.330	103.174	42.554	25.460	-1.430	21.826	-0.654	20.368	-3.414	17.461	-1.561
	9	125	41.000	94.611	44.747	99.728	42.206	30.389	-3.747	25.272	-1.206	24.311	-9.140	20.218	-2.942
	10	125	40.600	103.041	41.768	114.477	39.779	10.523	-1.168	10.523	0.821	8.418	-2.876	8.418	2.022
average								**25.700**	**-1.907**	**20.569**	**-0.575**	**20.560**	**-4.802**	**16.455**	**-1.443**

Appendix B1. Results of the Brick Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Brick 200 kg(weight) - 125 cm (width)	1	125	46.700	103.530	46.939	112.255	47.280	21.470	-0.239	12.745	-0.580	17.176	-0.511	10.196	-1.241
	2	125	46.000	107.262	44.994	118.511	43.771	17.738	1.006	6.489	2.229	14.191	2.187	5.192	4.847
	3	125	42.600	109.835	43.859	122.823	43.859	15.165	-1.259	2.177	-1.259	12.132	-2.954	1.742	-2.954
	4	125	47.400	106.760	47.233	117.701	44.210	18.240	0.167	7.299	3.190	14.592	0.353	5.839	6.731
	5	125	48.000	112.302	49.045	121.292	45.232	12.698	-1.045	3.708	2.768	10.158	-2.176	2.966	5.766
	6	125	44.300	124.114	45.277	126.229	43.865	0.886	-0.977	-1.229	0.435	0.709	-2.205	-0.984	0.981
	7	125	41.500	108.574	41.999	121.663	42.658	16.426	-0.499	3.337	-1.158	13.141	-1.202	2.670	-2.791
	8	125	47.000	116.720	45.182	129.004	43.111	8.280	1.818	-4.004	3.889	6.624	3.868	-3.203	8.274
	9	125	44.000	114.707	45.685	127.598	42.862	10.293	-1.685	-2.598	1.138	8.234	-3.830	-2.079	2.586
	10	125	41.000	108.486	40.977	121.800	42.059	3.200	0.023	3.200	-1.059	2.560	0.056	2.560	-2.583
average								**12.440**	**-0.269**	**3.112**	**0.959**	**9.952**	**-0.641**	**2.490**	**1.962**
Brick 200 kg(weight) - 150 cm (width)	1	150	42.300	117.254	41.941	130.387	43.588	32.746	0.359	19.613	-1.288	21.830	0.849	13.075	-3.045
	2	150	40.000	125.939	40.835	138.781	40.082	24.061	-0.835	11.219	-0.082	16.041	-2.087	7.479	-0.204
	3	150	43.300	121.223	42.745	133.790	40.108	28.777	0.555	16.210	3.192	19.185	1.282	10.807	7.372
	4	150	40.500	128.721	38.594	141.242	38.594	21.279	1.906	8.758	1.906	14.186	4.706	5.839	4.706
	5	150	40.200	121.846	43.375	135.678	39.706	28.154	-3.175	14.322	0.494	18.769	-7.899	9.548	1.229
	6	150	41.700	126.992	38.079	136.547	36.385	23.008	3.621	13.453	5.315	15.338	8.683	8.969	12.747
	7	150	47.500	118.613	43.240	131.600	38.911	31.387	4.260	18.400	8.589	20.924	8.969	12.267	18.082
	8	150	43.800	128.112	39.017	137.338	38.735	21.888	4.783	12.662	5.065	14.592	10.919	8.442	11.564
	9	150	43.400	117.479	44.901	131.551	40.619	32.521	-1.501	18.449	2.781	21.681	-3.458	12.299	6.409
	10	150	45.700	133.897	43.143	132.815	39.285	17.185	2.557	17.185	6.415	11.457	5.596	11.457	14.038
average								**26.100**	**1.253**	**15.027**	**3.239**	**17.400**	**2.756**	**10.018**	**7.290**

Appendix B1. Results of the Brick Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Brick 250 kg(weight) - 125 cm (width)	1	125	51.300	109.257	48.041	123.514	46.818	15.743	3.259	1.486	4.482	12.594	6.352	1.189	8.737
	2	125	49.300	114.079	47.129	129.475	45.387	10.921	2.171	-4.475	3.913	8.737	4.404	-3.580	7.938
	3	125	48.800	108.424	47.435	124.327	44.798	16.576	1.365	0.673	4.002	13.261	2.798	0.538	8.200
	4	125	50.900	124.533	49.813	134.043	47.836	0.467	1.087	-9.043	3.064	0.374	2.135	-7.235	6.020
	5	125	44.000	114.188	41.955	132.269	43.368	10.812	2.045	-7.269	0.632	8.650	4.647	-5.815	1.437
	6	125	45.000	114.696	44.411	133.419	43.517	10.304	0.589	-8.419	1.483	8.243	1.310	-6.735	3.296
	7	125	47.300	115.636	44.975	127.351	42.387	9.364	2.325	-2.351	4.913	7.491	4.916	-1.881	10.386
	8	125	42.300	115.694	43.333	128.492	43.051	9.306	-1.033	-3.492	-0.751	7.444	-2.442	-2.793	-1.775
	9	125	47.600	116.140	45.882	133.975	46.164	8.860	1.718	-8.975	1.436	7.088	3.610	-7.180	3.017
	10	125	42.700	120.193	43.171	131.114	44.348	-6.114	-0.471	-6.114	-1.648	-4.891	-1.103	-4.891	-3.860
average								**8.624**	**1.306**	**-4.798**	**2.153**	**6.899**	**2.663**	**-3.838**	**4.340**
Brick 250 kg(weight) - 150 cm (width)	1	150	49.300	121.787	46.493	132.282	44.753	28.213	2.807	17.718	4.547	18.808	5.693	11.812	9.224
	2	150	47.000	126.450	44.613	138.781	43.155	23.550	2.387	11.219	3.845	15.700	5.078	7.479	8.182
	3	150	49.000	116.278	46.248	132.479	43.422	33.722	2.752	17.521	5.578	22.481	5.617	11.681	11.384
	4	150	46.300	122.153	44.372	137.398	43.431	27.847	1.928	12.602	2.869	18.565	4.165	8.401	6.197
	5	150	47.000	131.405	44.461	141.710	44.414	18.595	2.539	8.290	2.586	12.396	5.403	5.527	5.503
	6	150	54.800	123.887	52.530	131.796	48.718	26.113	2.270	18.204	6.082	17.408	4.143	12.136	11.099
	7	150	43.200	117.943	42.074	133.683	42.426	32.057	1.126	16.317	0.774	21.371	2.606	10.878	1.792
	8	150	45.100	127.871	43.534	139.025	41.180	22.129	1.566	10.975	3.920	14.753	3.473	7.317	8.691
	9	150	45.200	120.280	42.210	134.818	40.987	29.720	2.990	15.182	4.213	19.813	6.614	10.121	9.321
	10	150	59.500	136.055	55.411	130.924	47.078	19.076	4.089	19.076	12.422	12.717	6.873	12.717	20.877
average								**26.102**	**2.445**	**14.710**	**4.684**	**17.401**	**4.966**	**9.807**	**9.227**

Appendix B1. Results of the Brick Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Brick 300 kg(weight) - 150 cm (width)	1	150	52.800	121.841	48.068	138.602	46.797	28.159	4.732	11.398	6.003	18.773	8.962	7.598	11.370
	2	150	50.300	126.388	48.062	139.052	47.214	23.612	2.238	10.948	3.086	15.741	4.449	7.299	6.135
	3	150	53.000	134.453	50.008	140.569	48.126	15.547	2.992	9.431	4.874	10.365	5.645	6.287	9.195
	4	150	50.700	125.497	48.580	140.751	45.332	24.503	2.120	9.249	5.368	16.335	4.181	6.166	10.588
	5	150	51.000	124.968	47.833	136.349	46.986	25.032	3.167	13.651	4.014	16.688	6.210	9.100	7.870
	6	150	47.300	136.764	46.341	144.291	45.541	13.236	0.959	5.709	1.759	8.824	2.027	3.806	3.718
	7	150	46.300	131.340	47.577	138.542	47.011	18.660	-1.277	11.458	-0.711	12.440	-2.757	7.639	-1.537
	8	150	43.800	135.531	51.059	141.318	48.424	14.469	-7.259	8.682	-4.624	9.646	-16.573	5.788	-10.558
	9	150	46.400	124.627	44.710	139.875	45.652	25.373	1.690	10.125	0.748	16.915	3.641	6.750	1.611
	10	150	48.400	131.413	45.780	141.575	45.921	8.425	2.620	8.425	2.479	5.617	5.413	5.617	5.121
average								**20.436**	**-2.662**	**4.764**	**-1.224**	**13.624**	**-5.815**	**3.176**	**-2.721**
Brick 300 kg(weight) - 175 cm (width)	1	175	50.800	139.658	51.165	143.047	49.141	35.342	-0.365	31.953	1.659	20.196	-0.719	18.259	3.266
	2	175	49.500	146.609	51.632	147.503	48.290	28.391	-2.132	27.497	1.210	16.223	-4.306	15.712	2.444
	3	175	48.300	121.423	45.728	131.820	43.705	53.577	2.572	43.180	4.595	30.615	5.326	24.674	9.513
	4	175	49.400	122.139	45.560	127.974	42.407	52.861	3.840	47.026	6.993	30.207	7.772	26.872	14.155
	5	175	49.700	133.336	47.143	138.888	44.414	41.664	2.557	36.112	5.286	23.808	5.145	20.635	10.635
	6	175	48.800	116.095	43.701	135.559	40.513	58.905	5.099	39.441	8.287	33.660	10.450	22.537	16.982
	7	175	47.000	134.403	44.299	140.051	43.593	40.597	2.701	34.949	3.407	23.198	5.748	19.971	7.249
	8	175	51.600	133.064	46.723	140.498	44.511	41.936	4.877	34.502	7.089	23.963	9.452	19.716	13.738
	9	175	51.000	137.460	47.671	146.166	44.189	37.540	3.329	28.834	6.811	21.451	6.527	16.476	13.356
	10	175	48.800	134.489	45.568	137.550	41.238	37.450	3.232	37.450	7.562	21.400	6.623	21.400	15.497
average								**42.826**	**2.571**	**36.094**	**5.290**	**24.472**	**5.202**	**20.625**	**10.684**

Appendix B2. Results of the Roof Tile Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Roof Tile 150 kg(weight) - 100 cm (width)	1	100	57.800	113.558	52.447	127.492	45.903	-13.558	5.353	-27.49	11.897	-13.55	9.262	-27.49	20.584
	2	100	48.000	105.216	45.214	121.558	41.917	-5.216	2.786	-21.55	6.083	-5.216	5.805	-21.55	12.673
	3	100	48.800	95.600	43.493	119.745	41.939	4.400	5.307	-19.74	6.861	4.400	10.875	-19.74	14.059
	4	100	55.500	98.742	50.006	114.125	47.183	1.258	5.494	-14.12	8.317	1.258	9.899	-14.12	14.985
	5	100	44.000	94.735	40.567	109.983	42.638	5.265	3.433	-9.983	1.362	5.265	7.802	-9.983	3.096
	6	100	43.000	101.690	41.194	119.485	40.393	-1.690	1.806	-19.48	2.607	-1.690	4.200	-19.48	6.062
	7	100	43.800	95.302	38.704	112.015	40.917	4.698	5.096	-12.01	2.883	4.698	11.634	-12.01	6.582
	8	100	43.800	99.540	43.330	103.174	42.554	0.460	0.470	-3.174	1.246	0.460	1.072	-3.174	2.845
	9	100	48.600	109.025	52.043	121.545	47.950	-9.025	-3.443	-21.54	0.650	-9.025	-7.085	-21.54	1.338
	10	100	45.000	116.557	48.090	125.402	45.738	-25.402	-3.090	-25.40	-0.738	-25.40	-6.867	-25.40	-1.640
average								**-3.881**	**2.321**	**-17.45**	**4.117**	**-3.881**	**4.660**	**-17.45**	**8.058**
Roof Tile 150 kg(weight) - 125 cm (width)	1	125	46.700	121.608	46.074	122.267	45.414	3.392	0.626	2.733	1.286	2.714	1.341	2.187	2.753
	2	125	43.500	113.523	43.205	121.521	40.946	11.477	0.295	3.479	2.554	9.182	0.677	2.783	5.872
	3	125	42.050	119.329	43.493	124.508	43.308	5.671	-1.443	0.492	-1.258	4.536	-3.432	0.393	-2.992
	4	125	50.000	107.847	48.042	114.481	46.725	17.153	1.958	10.519	3.275	13.722	3.916	8.415	6.551
	5	125	42.850	118.330	45.844	122.753	43.773	6.670	-2.994	2.247	-0.923	5.336	-6.987	1.798	-2.153
	6	125	40.200	106.030	40.738	119.332	40.609	18.970	-0.538	5.668	-0.409	15.176	-1.338	4.534	-1.017
	7	125	48.000	106.804	47.072	118.526	44.624	18.196	0.928	6.474	3.376	14.557	1.934	5.179	7.034
	8	125	41.300	113.873	41.897	119.474	42.415	11.127	-0.597	5.526	-1.115	8.901	-1.446	4.421	-2.700
	9	125	41.000	109.773	45.143	118.764	45.708	15.227	-4.143	6.236	-4.708	12.181	-10.104	4.989	-11.483
	10	125	40.600	113.165	47.525	115.612	46.442	9.388	-6.925	9.388	-5.842	7.511	-17.056	7.511	-14.389
average								**11.727**	**-1.283**	**5.276**	**-0.376**	**9.382**	**-3.249**	**4.221**	**-1.253**

Appendix B2. Results of the Roof Tile Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Roof Tile 200 kg(weight) - 125 cm (width)	1	125	45.500	115.052	47.526	128.088	50.960	9.948	-2.026	-3.088	-5.460	7.959	-4.453	-2.470	-12.001
	2	125	48.000	117.937	48.003	118.077	47.156	7.063	-0.003	6.923	0.844	5.650	-0.006	5.539	1.757
	3	125	48.800	121.911	49.423	125.205	51.871	3.089	-0.623	-0.205	-3.071	2.472	-1.277	-0.164	-6.292
	4	125	54.500	113.514	51.721	122.692	51.909	11.486	2.779	2.308	2.591	9.189	5.098	1.847	4.754
	5	125	51.000	117.645	52.799	125.456	52.328	7.355	-1.799	-0.456	-1.328	5.884	-3.527	-0.365	-2.604
	6	125	44.000	119.532	45.442	126.682	47.465	5.468	-1.442	-1.682	-3.465	4.374	-3.278	-1.346	-7.875
	7	125	46.600	112.730	48.414	123.081	50.296	12.270	-1.814	1.919	-3.696	9.816	-3.893	1.535	-7.930
	8	125	51.800	111.105	52.258	119.046	50.729	13.895	-0.458	5.954	1.071	11.116	-0.885	4.763	2.067
	9	125	45.050	107.084	42.476	123.660	43.935	17.916	2.574	1.340	1.115	14.332	5.714	1.072	2.474
	10	125	46.150	105.538	44.464	123.322	44.699	1.678	1.686	1.678	1.451	1.343	3.654	1.343	3.144
average								**9.017**	**-0.113**	**1.469**	**-0.995**	**7.213**	**-0.285**	**1.175**	**-2.250**
Roof Tile 200 kg(weight) - 150 cm (width)	1	150	46.000	119.706	42.789	122.058	39.446	30.294	3.211	27.942	6.554	20.196	6.981	18.628	14.248
	2	150	48.550	119.556	42.598	121.438	43.162	30.444	5.952	28.562	5.388	20.296	12.260	19.041	11.098
	3	150	46.150	114.038	41.682	121.707	38.765	35.962	4.468	28.293	7.385	23.975	9.682	18.862	16.002
	4	150	46.450	110.294	40.042	122.623	39.572	39.706	6.408	27.377	6.878	26.471	13.794	18.251	14.807
	5	150	47.950	113.014	43.145	122.566	40.651	36.986	4.805	27.434	7.299	24.657	10.021	18.290	15.222
	6	150	48.500	116.576	42.939	125.285	40.915	33.424	5.561	24.715	7.585	22.283	11.466	16.476	15.640
	7	150	52.100	113.687	45.447	113.546	39.937	36.313	6.653	36.454	12.163	24.208	12.770	24.303	23.346
	8	150	42.500	120.122	42.599	121.676	40.339	29.878	-0.099	28.324	2.161	19.919	-0.232	18.883	5.085
	9	150	45.700	115.299	41.867	119.062	41.773	34.701	3.833	30.938	3.927	23.134	8.387	20.625	8.593
	10	150	44.150	119.573	40.705	125.173	41.175	24.827	3.445	24.827	2.975	16.551	7.803	16.551	6.738
average								**33.253**	**4.424**	**28.487**	**6.232**	**22.169**	**9.293**	**18.991**	**13.078**

Appendix B2. Results of the Roof Tile Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Roof Tile 250 kg(weight) - 125 cm (width)	1	125	45.000	109.643	45.693	135.571	43.387	15.357	-0.693	-10.57	1.613	12.286	-1.540	-8.457	3.585
	2	125	44.500	118.151	46.724	127.987	42.631	6.849	-2.224	-2.987	1.869	5.480	-4.999	-2.390	4.199
	3	125	42.000	109.517	47.346	136.861	43.581	15.483	-5.346	-11.86	-1.581	12.387	-12.728	-9.489	-3.765
	4	125	40.700	115.476	46.397	136.604	42.445	9.524	-5.697	-11.60	-1.745	7.619	-13.999	-9.284	-4.287
	5	125	41.000	115.034	49.280	128.166	45.138	9.966	-8.280	-3.166	-4.138	7.973	-20.195	-2.533	-10.093
	6	125	40.300	118.405	47.249	130.547	43.626	6.595	-6.949	-5.547	-3.326	5.276	-17.244	-4.438	-8.252
	7	125	41.500	119.156	47.248	138.685	44.471	5.844	-5.748	-13.68	-2.971	4.675	-13.851	-10.94	-7.160
	8	125	37.000	112.850	49.742	132.521	47.577	12.150	-12.74	-7.521	-10.577	9.720	-34.438	-6.017	-28.588
	9	125	41.800	113.506	47.416	136.837	43.700	11.494	-5.616	-11.83	-1.900	9.195	-13.435	-9.470	-4.545
	10	125	37.800	110.564	48.084	133.289	44.602	-8.289	-10.28	-8.289	-6.802	-6.631	-27.206	-6.631	-17.996
average								**8.497**	**-6.358**	**-8.707**	**-2.956**	**6.798**	**-15.963**	**-6.966**	**-7.690**
Roof Tile 250 kg(weight) - 150 cm (width)	1	150	54.000	103.918	43.657	125.466	40.834	46.08	10.343	24.53	13.166	30.72	19.154	16.36	24.382
	2	150	54.800	126.646	47.657	130.974	47.045	23.35	7.143	19.03	7.755	15.57	13.035	12.68	14.151
	3	150	51.800	124.351	47.472	127.927	48.554	25.65	4.328	22.07	3.246	17.10	8.355	14.72	6.266
	4	150	46.800	126.937	43.677	133.902	43.489	23.06	3.123	16.10	3.311	15.38	6.674	10.73	7.075
	5	150	49.600	125.424	45.839	127.776	45.322	24.58	3.761	22.22	4.278	16.38	7.582	14.82	8.624
	6	150	48.700	130.533	47.009	131.332	47.761	19.47	1.691	18.67	0.939	12.98	3.472	12.45	1.928
	7	150	47.600	116.955	44.522	127.878	45.748	33.05	3.078	22.12	1.852	22.03	6.467	14.75	3.890
	8	150	59.000	121.273	44.990	123.861	45.084	28.73	14.010	26.14	13.916	19.15	23.746	17.43	23.587
	9	150	51.500	131.494	46.686	129.658	44.945	18.51	4.814	20.34	6.555	12.34	9.347	13.56	12.728
	10	150	49.800	131.865	44.175	130.358	44.834	19.64	5.625	19.64	4.966	13.09	11.296	13.09	9.972
average								**26.211**	**5.792**	**21.087**	**5.998**	**17.474**	**10.913**	**14.058**	**11.260**

Appendix B2. Results of the Roof Tile Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Roof Tile 300 kg(weight) - 150 cm (width)	1	150	54.150	121.841	48.068	138.602	46.797	28.16	6.082	11.40	7.353	18.773	11.231	7.598	13.580
	2	150	57.500	114.317	46.451	122.459	47.440	35.68	11.049	27.54	10.060	23.789	19.215	18.361	17.496
	3	150	53.100	127.245	48.658	134.351	45.458	22.76	4.442	15.65	7.642	15.170	8.365	10.433	14.392
	4	150	55.550	123.497	49.023	134.789	48.270	26.50	6.527	15.21	7.280	17.669	11.750	10.141	13.106
	5	150	54.600	129.937	48.097	133.561	48.050	20.06	6.503	16.44	6.550	13.375	11.910	10.959	11.996
	6	150	54.000	124.037	50.180	136.277	49.710	25.96	3.820	13.72	4.290	17.308	7.074	9.149	7.945
	7	150	52.500	130.372	46.813	133.195	47.049	19.63	5.687	16.80	5.451	13.085	10.832	11.203	10.383
	8	150	54.000	123.211	48.381	132.483	49.840	26.79	5.619	17.52	4.160	17.859	10.406	11.678	7.704
	9	150	55.050	127.535	49.507	131.674	50.450	22.47	5.543	18.33	4.600	14.977	10.069	12.217	8.356
	10	150	53.550	131.413	45.780	141.575	45.921	8.42	7.770	8.42	7.629	5.617	14.510	5.617	14.246
average								**23.643**	**6.304**	**16.103**	**6.502**	**15.762**	**11.536**	**10.736**	**11.920**
Roof Tile 300 kg(weight) - 175 cm (width)	1	175	63.000	134.605	54.171	138.182	52.947	40.395	8.829	36.818	10.053	23.083	14.014	21.039	15.957
	2	175	65.500	136.385	54.310	133.610	52.805	38.615	11.190	41.390	12.695	22.066	17.084	23.651	19.382
	3	175	68.200	136.083	55.920	133.918	51.307	38.917	12.280	41.082	16.893	22.238	18.005	23.476	24.769
	4	175	60.300	128.082	50.753	134.197	48.213	46.918	9.547	40.803	12.087	26.810	15.833	23.316	20.045
	5	175	58.700	136.197	51.533	134.832	50.450	38.803	7.167	40.168	8.250	22.173	12.210	22.953	14.055
	6	175	58.100	121.133	46.430	139.142	46.365	53.867	11.670	35.858	11.735	30.781	20.086	20.490	20.199
	7	175	52.600	131.960	47.861	139.818	46.402	43.040	4.739	35.182	6.198	24.594	9.009	20.104	11.784
	8	175	60.100	126.200	53.924	131.705	51.995	48.800	6.176	43.295	8.105	27.886	10.276	24.740	13.486
	9	175	55.800	128.210	49.514	137.152	48.055	46.790	6.286	37.848	7.745	26.737	11.265	21.628	13.880
	10	175	54.000	133.749	48.992	140.338	47.392	34.662	5.008	34.662	6.608	19.807	9.275	19.807	12.237
average								**43.081**	**8.289**	**38.711**	**10.037**	**24.617**	**13.706**	**22.120**	**16.579**

Appendix B3. Results of the Concrete-Mortar Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Concrete - mortar 150 kg(weight) - 100 cm (width)	1	100	42.300	92.592	37.898	102.684	40.226	7.408	4.402	-2.684	2.074	7.408	10.406	-2.684	4.902
	2	100	36.500	94.941	39.036	105.071	38.718	5.059	-2.536	-5.071	-2.218	5.059	-6.947	-5.071	-6.076
	3	100	35.600	95.234	37.837	106.143	39.378	4.766	-2.237	-6.143	-3.778	4.766	-6.283	-6.143	-10.613
	4	100	34.000	93.367	37.615	101.342	37.932	6.633	-3.615	-1.342	-3.932	6.633	-10.632	-1.342	-11.566
	5	100	34.600	92.710	37.006	101.882	37.394	7.290	-2.406	-1.882	-2.794	7.290	-6.955	-1.882	-8.076
	6	100	34.300	94.943	38.386	102.952	37.081	5.057	-4.086	-2.952	-2.781	5.057	-11.914	-2.952	-8.108
	7	100	34.200	99.181	37.612	104.368	36.412	0.819	-3.412	-4.368	-2.212	0.819	-9.976	-4.368	-6.468
	8	100	33.200	94.040	35.379	101.871	36.720	5.960	-2.179	-1.871	-3.520	5.960	-6.565	-1.871	-10.602
	9	100	33.200	94.686	40.252	99.236	38.100	5.314	-7.052	0.764	-4.900	5.314	-21.241	0.764	-14.759
	10	100	37.500	95.458	38.078	101.386	37.089	-1.386	-0.578	-1.386	0.411	-1.386	-1.540	-1.386	1.095
average								**4.692**	**-2.370**	**-2.694**	**-2.365**	**4.692**	**-7.165**	**-2.694**	**-7.027**
Concrete - mortar 150 kg(weight) - 125 cm (width)	1	125	31.700	102.632	33.607	109.985	31.008	22.368	-1.907	15.015	0.692	17.894	-6.016	12.012	2.184
	2	125	34.400	107.304	36.709	113.670	34.026	17.696	-2.309	11.330	0.374	14.156	-6.712	9.064	1.087
	3	125	34.000	115.287	40.893	120.279	40.374	9.713	-6.893	4.721	-6.374	7.770	-20.273	3.777	-18.748
	4	125	37.500	124.988	45.617	124.189	40.486	0.012	-8.117	0.811	-2.986	0.010	-21.646	0.649	-7.964
	5	125	35.500	112.676	41.842	125.997	36.570	12.324	-6.342	-0.997	-1.070	9.859	-17.864	-0.797	-3.014
	6	125	34.200	108.396	40.853	119.398	38.292	16.604	-6.653	5.602	-4.092	13.283	-19.453	4.481	-11.966
	7	125	33.500	112.038	40.295	118.723	36.954	12.962	-6.795	6.277	-3.454	10.370	-20.283	5.022	-10.309
	8	125	35.000	115.260	40.836	121.047	37.824	9.740	-5.836	3.953	-2.824	7.792	-16.674	3.162	-8.070
	9	125	39.000	117.229	44.614	117.557	39.909	7.771	-5.614	7.443	-0.909	6.217	-14.394	5.954	-2.330
	10	125	34.300	108.467	40.138	109.524	34.869	15.476	-5.838	15.476	-0.569	12.381	-17.021	12.381	-1.660
average								**12.467**	**-5.630**	**6.963**	**-2.121**	**9.973**	**-16.034**	**5.570**	**-6.079**

Appendix B3. Results of the Concrete-Mortar Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Concrete - mortar 200 kg(weight) - 125 cm (width)	1	125	43.300	115.590	48.522	121.660	45.180	9.410	-5.222	3.340	-1.880	7.528	-12.060	2.672	-4.343
	2	125	42.300	122.078	48.708	126.407	47.344	2.922	-6.408	-1.407	-5.044	2.338	-15.148	-1.126	-11.923
	3	125	36.500	128.022	45.340	128.868	40.774	-3.022	-8.840	-3.868	-4.274	-2.417	-24.220	-3.095	-11.710
	4	125	37.300	119.298	39.425	119.596	37.717	5.702	-2.125	5.404	-0.417	4.561	-5.698	4.323	-1.119
	5	125	37.100	110.064	38.480	116.971	36.998	14.936	-1.380	8.029	0.102	11.949	-3.721	6.423	0.274
	6	125	38.000	111.409	42.441	115.713	36.713	13.591	-4.441	9.287	1.287	10.872	-11.688	7.430	3.386
	7	125	44.900	122.577	50.132	126.295	44.342	2.423	-5.232	-1.295	0.558	1.939	-11.653	-1.036	1.242
	8	125	40.800	132.432	42.858	128.622	39.988	-7.432	-2.058	-3.622	0.812	-5.946	-5.045	-2.898	1.990
	9	125	40.500	126.717	46.177	126.482	40.575	-1.717	-5.677	-1.482	-0.075	-1.374	-14.016	-1.185	-0.186
	10	125	40.000	128.825	44.243	128.682	40.337	-3.682	-4.243	-3.682	-0.337	-2.946	-10.607	-2.946	-0.842
average								**3.313**	**-4.563**	**1.070**	**-0.927**	**2.650**	**-11.386**	**0.856**	**-2.323**

Concrete - mortar 200 kg(weight) - 150 cm (width)	1	150	45.000	107.905	40.977	122.223	37.067	42.095	4.023	27.777	7.933	28.063	8.941	18.518	17.628
	2	150	44.500	101.437	39.380	120.068	35.804	48.563	5.120	29.932	8.696	32.375	11.506	19.954	19.542
	3	150	42.000	121.223	42.745	133.790	40.108	28.777	-0.745	16.210	1.892	19.185	-1.773	10.807	4.505
	4	150	40.700	128.721	38.594	141.242	38.594	21.279	2.106	8.758	2.106	14.186	5.175	5.839	5.174
	5	150	41.000	121.846	43.375	135.678	39.706	28.154	-2.375	14.322	1.294	18.769	-5.793	9.548	3.157
	6	150	40.200	126.992	38.079	136.547	36.385	23.008	2.121	13.453	3.815	15.338	5.276	8.969	9.491
	7	150	41.500	118.613	43.240	131.600	38.911	31.387	-1.740	18.400	2.589	20.924	-4.192	12.267	6.238
	8	150	37.000	128.112	39.017	137.338	38.735	21.888	-2.017	12.662	-1.735	14.592	-5.453	8.442	-4.690
	9	150	41.800	117.479	44.901	131.551	40.619	32.521	-3.101	18.449	1.181	21.681	-7.418	12.299	2.826
	10	150	37.800	133.897	43.143	132.815	39.285	17.185	-5.343	17.185	-1.485	11.457	-14.134	11.457	-3.928
average								**29.486**	**-0.195**	**17.715**	**2.629**	**19.657**	**-0.786**	**11.810**	**5.994**

Appendix B3. Results of the Concrete-Mortar Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Concrete - mortar 250 kg(weight) - 125 cm (width)	1	125	51.300	138.292	51.447	146.719	57.191	-13.292	-0.147	-21.71	-5.891	-10.63	-0.287	-17.37	-11.483
	2	125	49.500	128.688	54.863	133.393	53.217	-3.688	-5.363	-8.393	-3.717	-2.951	-10.834	-6.715	-7.509
	3	125	48.800	130.201	50.489	133.071	51.713	-5.201	-1.689	-8.071	-2.913	-4.161	-3.462	-6.457	-5.969
	4	125	50.900	134.837	55.300	140.483	52.145	-9.837	-4.400	-15.48	-1.245	-7.869	-8.644	-12.38	-2.446
	5	125	44.000	139.754	51.637	140.084	50.176	-14.754	-7.637	-15.08	-6.176	-11.80	-17.357	-12.06	-14.037
	6	125	45.000	131.401	51.464	136.154	54.334	-6.401	-6.464	-11.15	-9.334	-5.120	-14.364	-8.923	-20.743
	7	125	47.300	137.183	53.133	135.442	55.484	-12.183	-5.833	-10.44	-8.184	-9.747	-12.331	-8.354	-17.303
	8	125	42.300	132.234	51.605	134.350	53.722	-7.234	-9.305	-9.350	-11.422	-5.787	-21.997	-7.480	-27.002
	9	125	47.600	120.598	49.970	129.019	49.358	4.402	-2.370	-4.019	-1.758	3.521	-4.979	-3.216	-3.693
	10	125	42.700	118.793	47.865	126.089	50.453	-1.089	-5.165	-1.089	-7.753	-0.871	-12.096	-0.871	-18.156
average								**-6.928**	**-4.837**	**-10.48**	**-5.839**	**-5.542**	**-10.635**	**-8.384**	**-12.834**
Concrete - mortar 250 kg(weight) - 150 cm (width)	1	150	42.500	132.055	46.810	134.642	44.693	17.945	-4.310	15.36	-2.193	11.96	-10.141	10.24	-5.159
	2	150	42.800	134.966	45.317	132.424	43.623	15.034	-2.517	17.58	-0.823	10.02	-5.882	11.72	-1.924
	3	150	44.700	131.069	47.234	132.292	42.530	18.931	-2.534	17.71	2.170	12.62	-5.669	11.81	4.856
	4	150	45.500	131.338	46.241	132.561	43.042	18.662	-0.741	17.44	2.458	12.44	-1.629	11.63	5.401
	5	150	46.500	122.054	49.095	129.963	40.576	27.946	-2.595	20.04	5.924	18.63	-5.581	13.36	12.741
	6	150	46.000	134.819	46.493	137.972	41.316	15.181	-0.493	12.03	4.684	10.12	-1.071	8.02	10.182
	7	150	48.000	129.071	49.520	129.589	43.400	20.929	-1.520	20.41	4.600	13.95	-3.166	13.61	9.583
	8	150	43.000	135.941	44.859	136.129	43.305	14.059	-1.859	13.87	-0.305	9.37	-4.323	9.25	-0.710
	9	150	45.000	127.162	46.592	134.363	42.733	22.838	-1.592	15.64	2.267	15.23	-3.538	10.42	5.037
	10	150	43.000	130.100	52.623	134.055	44.763	15.945	-9.623	15.94	-1.763	10.63	-22.380	10.63	-4.099
average								**7.984**	**6.911**	**9.151**	**7.100**	**3.080**	**2.365**	**7.329**	**3.591**

Appendix B3. Results of the Concrete-Mortar Waste Model

Model Material	No	Dimension of Model (in cm)		Measurement Based on the Q_{CWI} Tool (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in cm)				Differences of Measurement Based on the Q_{CWI} Tool Vs Model Design (in %)			
				Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape		Ordinary Image		Smoothed Shape	
		width	height	width	height	width	height	width	height	width	height	width	height	width	height
Concrete - mortar 300 kg(weight) - 150 cm (width)	1	150	49.200	131.776	52.080	145.090	50.292	18.224	-2.880	4.910	-1.092	12.15	-5.854	3.273	-2.220
	2	150	46.000	131.059	47.812	147.107	47.342	18.941	-1.812	2.893	-1.342	12.63	-3.939	1.929	-2.917
	3	150	47.000	131.656	49.377	145.873	48.389	18.344	-2.377	4.127	-1.389	12.23	-5.058	2.752	-2.955
	4	150	46.300	131.858	50.370	145.792	49.052	18.142	-4.070	4.208	-2.752	12.09	-8.790	2.805	-5.945
	5	150	44.600	130.372	47.066	143.974	46.972	19.628	-2.466	6.026	-2.372	13.09	-5.530	4.017	-5.319
	6	150	44.300	130.157	48.280	144.885	46.584	19.843	-3.980	5.115	-2.284	13.23	-8.983	3.410	-5.156
	7	150	47.700	128.200	49.558	144.248	46.828	21.800	-1.858	5.752	0.872	14.53	-3.894	3.835	1.828
	8	150	43.500	126.607	47.583	146.091	45.465	23.393	-4.083	3.909	-1.965	15.60	-9.386	2.606	-4.517
	9	150	48.200	124.387	48.635	144.066	46.893	25.613	-0.435	5.934	1.307	17.08	-0.902	3.956	2.711
	10	150	44.500	128.934	48.503	145.181	47.373	4.819	-4.003	4.819	-2.873	3.21	-8.997	3.213	-6.457
average								**20.436**	**-2.662**	**4.764**	**-1.224**	**13.624**	**-5.815**	**3.176**	**-2.721**
Concrete - mortar 300 kg(weight) - 175 cm (width)	1	175	46.000	137.032	50.351	144.561	42.305	37.97	-4.351	30.44	3.695	21.70	-9.460	17.39	8.032
	2	175	45.000	147.803	48.091	149.025	43.056	27.20	-3.091	25.97	1.944	15.54	-6.869	14.84	4.319
	3	175	44.800	140.376	51.028	148.333	43.544	34.62	-6.228	26.67	1.256	19.79	-13.902	15.24	2.803
	4	175	44.000	143.372	46.927	149.161	42.832	31.63	-2.927	25.84	1.168	18.07	-6.653	14.76	2.654
	5	175	48.700	129.313	49.079	149.545	41.927	45.69	-0.379	25.46	6.773	26.11	-0.779	14.55	13.907
	6	175	45.300	125.142	45.947	145.861	44.168	49.86	-0.647	29.14	1.132	28.49	-1.429	16.65	2.498
	7	175	48.500	136.165	47.662	145.997	43.616	38.84	0.838	29.00	4.884	22.19	1.727	16.57	10.071
	8	175	50.000	129.541	49.237	144.697	41.752	45.46	0.763	30.30	8.248	25.98	1.526	17.32	16.495
	9	175	43.800	138.906	48.766	146.861	43.070	36.09	-4.966	28.14	0.730	20.63	-11.338	16.08	1.667
	10	175	43.300	117.107	32.379	147.437	45.144	27.56	10.921	27.56	-1.844	15.75	25.221	15.75	-4.258
Average								37.49	-1.01	27.85	2.80	21.42	-2.20	15.92	5.82

APPENDIX C

C1. Quantification of the Waste Stack Based on the Area Method

Appendix C. Volume of the Bricks Waste Model Based on Area Method

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON AREA METHOD

No. of Slice	IMAGE 1 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)
	Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter		
	X	Y					X	Y					X	Y				
1	1802	1202	150	1050	0.0011	0.0249	2738	1202	150	2358	0.0054	0.0299	2150	1196	144	1965	0.0038	0.02383
	752	1202	147				380	1199	150				185	1202	150			
2	2957	1052	150	2937	0.0084	0.04398	2738	1052	150	2451	0.0059	0.03453	2540	1052	150	2355	0.0054	0.03318
	20	1055	156				287	1049	147				185	1052	150			
3	2912	902	150	2838	0.0079	0.03782	2756	902	150	2736	0.0073	0.03549	2762	902	150	2700	0.0071	0.03318
	74	899	144				20	902	150				62	902	150			
4	2774	752	150	2622	0.0067	0.03174	2687	752	147	2499	0.0061	0.0305	2729	752	150	2355	0.0054	0.0258
	152	755	150				188	752	150				374	752	150			
5	2579	602	150	2325	0.0053	0.02145	2558	605	153	2382	0.0055	0.02187	2678	602	150	2106	0.0043	0.01841
	254	605	153				176	602	144				572	602	153			
6	2153	452	150	1677	0.0027	0.01059	2297	452	150	1695	0.0028	0.01174	2429	452	150	1617	0.0026	0.01042
	476	452	150				602	458	159				812	449	144			
7	2093	302	150	1134	0.0013	0.00491	2150	302	150	1239	0.0015	0.00592	2072	302	150	1224	0.0015	0.0048
	959	302	150				911	299	147				848	305	153			
8	1718	152	132	783	0.0006	0.00139	1937	152	126	882	0.0008	0.00169	1934	152	129	582	0.0003	0.00075
	935	152	132				1055	152	126				1352	152	129			
Height	**1352**	**1271**	**1182**	**TOTAL**	**0.0042**	**0.17679**	**1352**	**1202**	**1174.5**	**TOTAL**	**0.0044**	**0.17164**	**1499**	**1202**	**1176**	**TOTAL**	**0.0038**	**0.15036**
	1352	**20**	**1251**				**1352**	**26**	**1176**				**1502**	**23**	**1179**			

Material type	=	**Brick**	**Density =**	**911 kg/m3**
Average of Volume	=	**0.1663 m^3**		
Weight of the waste stack	=	**151.46 kg**		

Appendix C. Volume of the Brick Waste Model Based on the Area Methods

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel)				Area per slice	Vol. between two slices	IMAGE 2 (in pixel)				Area per slice	Vol. between two slices	IMAGE 3 (in pixel)				Area per slice	Vol. between two slices
	Coordinate		Height per slice	Dia-meter	(m^2)	(m^3)	Coordinate		Height per slice	Dia-meter	(m^2)	(m^3)	Coordinate		Height per slice	Dia-meter	(m^2)	(m^3)
	X	Y					X	Y					X	Y				
1	1802	1202	150	1050	0.0011	0.02465	1805	1190	138	1434	0.002	0.01886	2057	1205	156	1086	0.0012	0.02237
	752	1202	150				371	1187	135				971	1202	150			
2	2939	1052	150	2904	0.0082	0.04275	2720	1052	150	2442	0.0058	0.03464	2726	1049	147	2703	0.0071	0.04028
	35	1052	150				278	1052	150				23	1052	153			
3	2927	902	150	2847	0.0079	0.03884	2747	902	150	2727	0.0073	0.03544	2933	902	147	2877	0.0081	0.03509
	80	902	150				20	902	150				56	899	147			
4	2792	752	150	2631	0.0068	0.03194	2672	752	150	2505	0.0061	0.03078	2723	755	153	2361	0.0054	0.02485
	161	752	150				167	752	150				362	752	150			
5	2594	602	150	2331	0.0053	0.02134	2540	602	150	2373	0.0055	0.02209	2660	602	150	1986	0.0039	0.01722
	263	602	150				167	602	150				674	602	153			
6	2168	452	150	1680	0.0028	0.01064	2288	452	150	1707	0.0028	0.01161	2423	452	150	1629	0.0026	0.01055
	488	452	150				581	452	153				794	449	147			
7	2105	302	147	1137	0.0013	0.00484	2132	302	150	1239	0.0015	0.006	2051	302	150	1212	0.0014	0.00465
	968	302	147				893	299	147				839	302	150			
8	1730	155	144	786	0.0006	0.00153	1943	152	132	900	0.0008	0.00184	1925	152	120	573	0.0003	0.00068
	944	155	144				1043	152	132				1352	152	120			
Height	**1352**	**1259**	**1191**	**T O T A L**	**0.0042**	**0.17653**	**1352**	**1202**	**1168.5**	**T O T A L**	**0.004**	**0.16126**	**1502**	**1214**	**1171.5**	**T O T A L**	**0.0038**	**0.15569**
	1352	**11**	**1248**				**1352**	**20**	**1182**				**1502**	**32**	**1182**			

Material type	=	**Brick**	**Density** =	**911 kg/m3**
Average of Volume	=	**0.1645** m^3		
Weight of the waste stack	=	**149.85** kg		

Appendix C. Volume of the Brick Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)
1	2615	1202	150	2580	0.007	0.0347	2873	1253	201	2820	0.008	0.0554	2879	1268	219	2826	0.008	0.0546
	35	1202	153				53	1253	201				53	1262	210			
2	2618	1052	150	2574	0.006	0.0306	2852	1052	150	2838	0.008	0.0376	2684	1049	150	2604	0.007	0.0334
	44	1049	147				14	1052	150				80	1052	150			
3	2438	902	150	2313	0.005	0.0256	2762	902	150	2550	0.006	0.0305	2525	899	147	2478	0.006	0.0275
	125	902	150				212	902	150				47	902	150			
4	2405	752	150	2130	0.004	0.021	2732	752	150	2298	0.005	0.0227	2405	752	150	2145	0.004	0.0209
	275	752	150				434	752	150				260	752	150			
5	2234	602	150	1890	0.003	0.0152	2516	602	150	1872	0.003	0.0146	2306	602	150	1869	0.003	0.015
	344	602	150				644	602	150				437	602	150			
6	1967	452	150	1524	0.002	0.0094	2153	452	150	1461	0.002	0.0081	2225	452	150	1515	0.002	0.0106
	443	452	150				692	452	153				710	452	150			
7	1634	302	150	1152	0.001	0.0043	1859	302	150	981	9E-04	0.0035	2192	302	153	1344	0.002	0.0055
	482	302	150				878	299	150				848	302	150			
8	1433	152	138	567	3E-04	0.0008	1616	152	147	621	4E-04	0.001	1799	149	114	564	3E-04	0.0006
	866	152	138				995	149	144				1235	152	117			
Height	**1352**	**1226**	**1188**	TOTAL	**0.004**	**0.1415**	**1346**	**1256**	**1248**	TOTAL	**0.004**	**0.1733**	**1352**	**1274**	**1230**	TOTAL	**0.004**	**0.1681**
	1352	**14**	**1212**				**1352**	**5**	**1251**				**1352**	**35**	**1239**			

Material type	=	**Brick**	**Density**	=	**911 kg/m3**
Average of Volume	=	**0.161 m^3**			
Weight of the waste stack	=	**146.68 kg**			

Appendix C. Volume of the Bricks Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)
	Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter		
	X	Y					X	Y					X	Y				
1	2615	1202	150	2580	0.007	0.0347	2873	1253	201	2820	0.008	0.0554	2879	1268	219	2826	0.008	0.0546
	35	1202	153				53	1253	201				53	1262	210			
2	2618	1052	150	2574	0.006	0.0306	2852	1052	150	2838	0.008	0.0376	2684	1049	150	2604	0.007	0.0334
	44	1049	147				14	1052	150				80	1052	150			
3	2438	902	150	2313	0.005	0.0256	2762	902	150	2550	0.006	0.0305	2525	899	147	2478	0.006	0.0275
	125	902	150				212	902	150				47	902	150			
4	2405	752	150	2130	0.004	0.021	2732	752	150	2298	0.005	0.0227	2405	752	150	2145	0.004	0.0209
	275	752	150				434	752	150				260	752	150			
5	2234	602	150	1890	0.003	0.0152	2516	602	150	1872	0.003	0.0146	2306	602	150	1869	0.003	0.015
	344	602	150				644	602	150				437	602	150			
6	1967	452	150	1524	0.002	0.0094	2153	452	150	1461	0.002	0.0081	2225	452	150	1515	0.002	0.0106
	443	452	150				692	452	153				710	452	150			
7	1634	302	150	1152	0.001	0.0043	1859	302	150	981	9E-04	0.0035	2192	302	153	1344	0.002	0.0055
	482	302	150				878	299	150				848	302	150			
8	1433	152	138	567	3E-04	0.0008	1616	152	147	621	4E-04	0.001	1799	149	114	564	3E-04	0.0006
	866	152	138				995	149	144				1235	152	117			
Height	**1352**	**1226**	**1188**	**TOTAL**	**0.004**	**0.1415**	**1346**	**1256**	**1248**	**TOTAL**	**0.004**	**0.1733**	**1352**	**1274**	**1230**	**TOTAL**	**0.004**	**0.1681**
	1352	**14**	**1212**				**1352**	**5**	**1251**				**1352**	**35**	**1239**			

Material type	=	**Brick**	**Density**	=	**911 kg/m3**
Average of Volume	=	**0.161** m^3			
Weight of the waste stack	=	**146.68** **kg**			

Appendix C. Volume of the Brick Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)
	Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter			Coordinate		Height per slice	Dia-meter		
	X	Y					X	Y					X	Y				
1	1301	1205	153	216	5E-05	0.0209	2684	1151	99	2655	0.007	0.0246	2762	1184	132	2481	0.006	0.0287
	1085	1202	150				29	1154	102				281	1181	129			
2	2849	1052	150	2820	0.008	0.0395	2747	1052	150	2679	0.007	0.0369	2789	1052	150	2568	0.006	0.0357
	29	1052	150				68	1052	150				221	1052	150			
3	2792	902	150	2709	0.007	0.0335	2837	902	150	2664	0.007	0.0341	2735	902	150	2688	0.007	0.0327
	83	902	150				173	902	150				47	902	150			
4	2567	752	150	2373	0.006	0.0252	2783	752	150	2472	0.006	0.0292	2663	752	150	2331	0.005	0.0256
	194	752	150				311	752	150				332	752	150			
5	2336	602	147	2025	0.004	0.017	2606	602	150	2274	0.005	0.0225	2483	602	150	2115	0.004	0.0191
	311	602	150				332	602	150				368	602	150			
6	2210	455	153	1590	0.002	0.009	2387	452	150	1884	0.003	0.0132	2309	452	150	1704	0.003	0.0095
	620	452	150				503	452	150				605	452	150			
7	1907	302	150	960	9E-04	0.0032	1811	302	150	1251	0.002	0.0056	1799	302	150	879	8E-04	0.003
	947	302	150				560	302	150				920	302	150			
8	1730	152	117	558	3E-04	0.0006	1619	152	138	783	6E-04	0.0015	1718	152	105	612	4E-04	0.0007
	1172	152	117				836	152	138				1106	152	105			
Height	**1352**	**1241**	**1168.5**	**TOTAL**	**0.004**	**0.1489**	**1352**	**1202**	**1138.5**	**TOTAL**	**0.005**	**0.1677**	**1352**	**1178**	**1135.5**	**TOTAL**	**0.004**	**0.1549**
	1352	**35**	**1206**				**1352**	**14**	**1188**				**1352**	**47**	**1131**			

Material type	**=**	**Brick**	**Density**	**=**	**911 kg/m3**
Average of Volume	**=**	**0.1572 m^3**			
Weight of the waste stack	**=**	**143.18 kg**			

Appendix C. Volume of the Brick Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE

BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel) Coordinate X	IMAGE 1 Coordinate Y	IMAGE 1 Height per slice	IMAGE 1 Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel) Coordinate X	IMAGE 2 Coordinate Y	IMAGE 2 Height per slice	IMAGE 2 Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel) Coordinate X	IMAGE 3 Coordinate Y	IMAGE 3 Height per slice	IMAGE 3 Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)
1	2570	1202	150	2511	0.006	0.0328	2735	1202	150	2676	0.007	0.0369	2672	1202	150	2589	0.007	0.0343
	59	1202	150				59	1202	150				83	1202	147			
2	2579	1052	150	2526	0.006	0.0339	2726	1052	150	2667	0.007	0.0353	2681	1052	150	2592	0.007	0.0359
	53	1052	150				59	1052	150				89	1055	156			
3	2624	902	150	2592	0.007	0.0318	2618	902	150	2559	0.006	0.0339	2672	902	150	2628	0.007	0.0334
	32	902	150				59	902	153				44	899	147			
4	2519	752	150	2364	0.005	0.0239	2615	752	150	2535	0.006	0.025	2657	752	150	2481	0.006	0.0268
	155	752	150				80	749	147				176	752	150			
5	2273	602	150	1917	0.004	0.0171	2270	602	150	1833	0.003	0.0154	2360	602	150	2049	0.004	0.018
	356	602	153				437	602	153				311	602	150			
6	2180	452	150	1695	0.003	0.0105	2201	452	150	1599	0.002	0.0097	2189	452	150	1668	0.003	0.01
	485	449	147				602	449	147				521	452	150			
7	1748	302	150	1101	0.001	0.0049	2045	302	150	1113	0.001	0.0046	1952	302	150	1044	0.001	0.0047
	647	302	150				932	302	150				908	302	150			
8	1673	152	117	822	7E-04	0.0014	1733	152	132	726	5E-04	0.0012	1823	152	138	855	7E-04	0.0017
	851	152	117				1007	152	132				968	152	138			
Height	**1349**	**1202**	**1167**	**T O T A L**	**0.004**	**0.1562**	**1352**	**1241**	**1182**	**T O T A L**	**0.004**	**0.162**	**1352**	**1181**	**1188**	**T O T A L**	**0.004**	**0.165**
	1352	**35**	**1167**				**1352**	**20**	**1221**				**1352**	**14**	**1167**			

Material type	=	**Brick**	**Density**	=	**911 kg/m3**
Average of Volume	=	**0.1611** m^3			
Weight of the waste stack	=	**146.73 kg**			

Appendix C. Volume of the Bricks Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)
1	2690	1352	150	2640	0.007	0.0364	2678	1352	150	2649	0.007	0.0371	2684	1352	150	2547	0.006	0.0371
	50	1352	150				29	1352	153				137	1352	150			
2	2702	1202	150	2670	0.007	0.036	2720	1202	150	2679	0.007	0.0347	2843	1202	150	2802	0.008	0.0362
	32	1202	150				41	1199	147				41	1202	150			
3	2729	1052	150	2607	0.007	0.0322	2681	1052	150	2529	0.006	0.0285	2759	1052	150	2481	0.006	0.029
	122	1052	150				152	1052	150				278	1052	150			
4	2675	902	150	2376	0.006	0.0228	2414	902	150	2151	0.005	0.0222	2573	902	150	2250	0.005	0.0227
	299	902	150				263	902	150				323	902	150			
5	2369	752	150	1782	0.003	0.0122	2306	752	150	1986	0.004	0.0169	2453	752	150	1929	0.004	0.0169
	587	752	150				320	752	147				524	752	150			
6	1970	602	150	1236	0.001	0.0069	2117	602	150	1629	0.003	0.011	2330	602	150	1680	0.003	0.0113
	734	602	153				488	605	153				650	602	150			
7	1916	452	147	1065	0.001	0.0048	1991	452	147	1242	0.002	0.0068	2021	452	150	1239	0.001	0.006
	851	449	150				749	452	153				782	452	150			
8	1754	305	294	852	7E-04	0.0036	1988	305	294	1035	0.001	0.0054	1784	302	291	897	8E-04	0.004
	902	299	288				953	299	288				887	302	291			
Height	**1352**	**1379**	**1341**	**TOTAL**	**0.004**	**0.1549**	**1352**	**1409**	**1341**	**TOTAL**	**0.004**	**0.1624**	**1352**	**1379**	**1341**	**TOTAL**	**0.004**	**0.1632**
	1352	**11**	**1368**				**1352**	**11**	**1398**				**1352**	**11**	**1368**			

Material type	**=**	**Brick**	**Density =**	**911 kg/m3**
Average of Volume	**=**	**0.1602 m^3**		
Weight of the waste stack	**=**	**145.92 kg**		

Appendix C. Volume of the Brick Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)
1	2891	1202	150	2796	0.008	0.0405	2822	1202	150	2790	0.008	0.0386	2780	1202	150	2529	0.006	0.0365
	95	1202	150				32	1202	150				251	1202	150			
2	2900	1052	150	2805	0.008	0.0391	2717	1052	150	2676	0.007	0.0342	2798	1052	150	2781	0.008	0.0381
	95	1052	150				41	1052	150				17	1052	153			
3	2738	902	150	2694	0.007	0.0319	2600	902	150	2463	0.006	0.0293	2747	902	150	2616	0.007	0.0315
	44	902	150				137	902	150				131	899	147			
4	2591	752	150	2256	0.005	0.0232	2513	752	150	2295	0.005	0.0237	2726	752	150	2337	0.005	0.0231
	335	752	153				218	752	150				389	752	150			
5	2447	602	150	1950	0.004	0.0167	2333	602	150	1971	0.004	0.0175	2447	602	150	1866	0.003	0.0157
	497	599	147				362	602	150				581	602	150			
6	2192	452	150	1647	0.003	0.012	2288	452	150	1698	0.003	0.0105	2381	452	150	1611	0.003	0.0121
	545	452	150				590	452	150				770	452	150			
7	2138	302	150	1392	0.002	0.0066	2021	302	150	1089	0.001	0.0038	2186	302	150	1440	0.002	0.0068
	746	302	153				932	302	150				746	302	150			
8	1832	152	135	768	6E-04	0.0014	1703	152	141	525	3E-04	0.0007	1826	152	135	744	5E-04	0.0013
	1064	149	132				1178	152	141				1082	152	135			
Height	**1352**	**1223**	**1185**	**T O T A L**	**0.005**	**0.1714**	**1352**	**1298**	**1191**	**T O T A L**	**0.004**	**0.1582**	**1352**	**1241**	**1185**	**T O T A L**	**0.004**	**0.165**
	1352	**17**	**1206**				**1352**	**11**	**1287**				**1352**	**17**	**1224**			

Material type	**=**	**Brick**	**Density**	**=**	**911**	**kg/m3**
Average of Volume	**=**	**0.1649**	**m^3**			
Weight of the waste stack	**=**	**150.22**	**kg**			

Appendix C. Volume of the Brick Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE

BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 2 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)	IMAGE 3 (in pixel)				Area per slice (m^2)	Vol. between two slices (m^3)
	Coordinate X	Coordinate Y	Height per slice	Dia-meter			Coordinate X	Coordinate Y	Height per slice	Dia-meter			Coordinate X	Coordinate Y	Height per slice	Dia-meter		
1	2699	1280	78	2550	0.006	0.0195	2702	1202	150	2661	0.007	0.0378	2642	1301	99	2598	0.007	0.0234
	149	1292	90				41	1205	153				44	1304	102			
2	2678	1202	150	2643	0.007	0.0354	2783	1052	150	2721	0.007	0.0369	2633	1202	150	2595	0.007	0.0338
	35	1202	150				62	1052	153				38	1202	150			
3	2678	1052	150	2589	0.007	0.0311	2660	902	150	2592	0.007	0.0322	2648	1052	150	2517	0.006	0.0313
	89	1052	150				68	899	147				131	1052	150			
4	2492	902	150	2307	0.005	0.0249	2666	752	150	2424	0.006	0.0253	2549	902	150	2406	0.006	0.0268
	185	902	150				242	752	153				143	902	150			
5	2435	752	150	2073	0.004	0.0192	2396	602	150	1950	0.004	0.0145	2498	752	150	2142	0.004	0.0206
	362	752	150				446	599	147				356	752	147			
6	2180	602	150	1767	0.003	0.012	2168	452	150	1371	0.002	0.0075	2318	602	150	1863	0.003	0.0138
	413	602	150				797	452	150				455	605	159			
7	2006	452	150	1233	0.001	0.0062	1964	302	150	1005	1E-03	0.0031	1898	452	150	1302	0.002	0.0073
	773	452	150				959	302	147				596	446	147			
8	1859	302	261	945	9E-04	0.004	1493	152	141	438	2E-04	0.0005	1805	302	288	1077	0.001	0.0057
	914	302	261				1055	155	144				728	299	285			
Height	**1352**	**1283**	**1245**	**T O T A L**	**0.004**	**0.1523**	**1352**	**1250**	**1192.5**	**T O T A L**	**0.004**	**0.1577**	**1352**	**1328**	**1288.5**	**T O T A L**	**0.004**	**0.1627**
	1352	**41**	**1242**				**1352**	**11**	**1239**				**1352**	**14**	**1314**			

Material type	=	**Brick**	**Densit**	=	**911 kg/m3**
Average of Volume	=	**0.1576** m^3			
Weight of the waste stack	=	**143.55 kg**			

Appendix C. Volume of the Brick Waste Model Based on the Area Method

QUANTIFICATION OF CONSTRUCTION WASTE
BASED ON THE AREA METHOD

No. of Slice	IMAGE 1 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)
1	2825	1349	147	2784	0.008	0.0404
	41	1352	153			
2	2846	1202	150	2805	0.008	0.0404
	41	1199	147			
3	2891	1052	150	2811	0.008	0.0371
	80	1052	150			
4	2663	902	150	2538	0.006	0.0284
	125	902	150			
5	2441	752	150	2130	0.004	0.0195
	311	752	147			
6	2234	602	150	1761	0.003	0.0113
	473	605	153			
7	1820	452	150	1104	0.001	0.0044
	716	452	147			
8	1724	302	264	696	5E-04	0.0022
	1028	305	267			
Height	**1352**	**1334**	**1312.5**	**T O T A L**	**0.005**	**0.1836**
	1355	**38**	**1296**			

No. of Slice	IMAGE 2 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)
1	2735	1304	102	2364	0.005	0.0222
	371	1304	105			
2	2726	1202	150	2616	0.007	0.0338
	110	1199	147			
3	2567	1052	150	2526	0.006	0.0318
	41	1052	150			
4	2543	902	150	2433	0.006	0.0255
	110	902	147			
5	2303	752	150	2013	0.004	0.0186
	290	755	153			
6	2213	602	150	1749	0.003	0.0131
	464	602	150			
7	1979	452	150	1413	0.002	0.0067
	566	452	150			
8	1643	302	273	780	6E-04	0.0029
	863	302	273			
Height	**1352**	**1325**	**1275**	**T O T A L**	**0.004**	**0.1546**
	1352	**29**	**1296**			

No. of Slice	IMAGE 3 (in pixel) Coordinate X	Y	Height per slice	Dia-meter	Area per slice (m^2)	Vol. between two slices (m^3)
1	2861	1289	87	2814	0.008	0.0245
	47	1289	93			
2	2855	1202	150	2802	0.008	0.0372
	53	1196	147			
3	2858	1052	150	2589	0.007	0.0317
	269	1049	147			
4	2732	902	150	2385	0.006	0.0268
	347	902	150			
5	2669	752	150	2166	0.005	0.0202
	503	752	150			
6	2444	602	150	1767	0.003	0.0115
	677	602	150			
7	2171	452	150	1152	0.001	0.0047
	1019	452	150			
8	1877	302	288	687	5E-04	0.0023
	1190	302	288			
Height	**1652**	**1283**	**1275**	**T O T A L**	**0.005**	**0.1589**
	1649	**14**	**1269**			

Material type	=	**Brick**	**Densit**y	=	**911 kg/m3**
Average of Volume	=	**0.1657** m^3			
Weight of the waste stack	=	**150.94 kg**			

BIOGRAPHY

Agus NUGROHO

I was born in Madiun, East Java Province, Indonesia on August 11^{th}, 1972. I completed elementary to senior high school in Madiun. In 1998, I finished my bachelor degree of Civil Engineering in Gadjah Mada University (UGM), Yogyakarta. After graduated, I joined the Faculty of Engineering UGM as a lecturer in Civil Engineering Diploma Program. In 2004, I continued study post graduate in Civil Engineering in Bandung Institute of Technology (ITB), Indonesia, and finished in 2006. By the end of 2008, I got scholarship from AUN/SEED-Net JICA to pursue doctoral sandwich program in Chulalongkorn University, Bangkok, Thailand and Hokkaido University Japan.