DEVELOPMENT OF AUTOMATIC FLOOR TILE LAYING MACHINE

by

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LIST OF SYMBOLS

S/N_L	Signal to noise ratio (Higher-the-better)
n	Number of experiments
y	Result for each level
F_o	Static Force (N)
m	Unbalance mass (N)
e	Eccentric (mm)
ω	Angular velocity (rad/s)
t	Time (s)
a	Acceleration (m/s^2)
v	Current velociy (m/s)
u	Initial velocity (m/s)
t	Time (s)
F_i	Inertia force (N)
F_f	Friction force (N)
T	Torque (Nm)
P	Power (Watt)
r	Radius (m)
A_o	Outer Area (m^2)
A_i	Inner Area (m^2)
A_t	Total Area (m^2)
Q	Volume per rotation (m^3)
F	Force (N)
T_{tf}	Theoritical force (N)
F_{tr}	Reverse stroke force (N)
F_r	Required force (N)
F_a	Accelaration force (N)

A	Acceleration of pneumatic force (m/s^2)
A_{sc}	Suction cup are (m^2)
P_{sc}	Suction cup vacuum pressure (kg/m^2)
Fhf	Holding force (N)

LIST OF ABBREVIATION

IDEF3	Integrated Definition Function 3
DOF	Degree of Freedom
UOB	Unit of Behavior
ANOVA	Analysis of Variance
DOE	Design of Experiment

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PEMBANGUNAN MESIN MEMASANG JUBIN LANTAI AUTOMATIK

ABSTRAK

Proses pemasangan jubin lantai merupakan kerja penyudah yang lazimnya dilakukan secara manual. Proses ini digambarkan secara terperinci termasuk aliran kerja pemasangan jubin lantai, ketebalan mortar, corak pemasangan jubin, peralatan, kecacatan pemasangan, kos dan kadar kerja. Analisa ke atas kos pemasangan jubin lantai telah dibuat berdasarkan data yang diperolehi dalam satu projek pembinaan di langkawi dalam tahun 2005. Kos buruh adalah sebanyak RM 1.50 bagi setiap kaki persegi. Walaubagaimanapun, kos bahan adalah berubah bergantung kepada kualiti dan rekabentuk jubin. Kajian lapangan telah dilakukan untuk mengukur kadar kerja pemasangan jubin dan secara purata ia mengambil masa 19.2 saat untuk memasang jubin bersaiz 300 mm x 300 mm. Penyelidikan terdahulu dan teknologi robot terkini turut dibincangkan termasuk kepelbagaian konfigurasi yang dipertimbangkan oleh penyelidik-penyelidik. Justeru itu, elemen-elemen penting untuk mengautomasikan pemasangan jubin lantai telah dikenalpasti dan didapati terdapat kekurangan data terhadap kerja pemasangan jubin, rekabentuk manipulator dan keberkesanan kos. Penyelidikan ini bermotivasi untuk mengurangkan masa pemasangan dan kos buruh sementara mengekalkan kualiti pemasangan. Proses pemasangan jubin lantai secara manual telah berjaya diperincikan menggunakan kaedah proses dan objek skematik, IDEF3. Untuk meningkatkan kadar kerja, aktiviti-aktiviti yang tidak penting atau tidak diperlukan telah dihapuskan atau digabungkan. Satu proses yang lebih ringkas telah berjaya dihasilkan dengan menggunakan IDEF3 dan dijadikan asas untuk penghasilan mesin baru dan di nilai untuk diautomasikan. Satu eksperimen telah dijalankan menggunakan kaedah Taguchi untuk menentukan parameter-parameter proses yang paling optimum bagi kekuatan lekatan antara jubin dan mortar. Parameter-parameter tersebut adalah daya yang dikenakan, ketebalan mortar, bentuk mortar, dan kelajuan getaran motor. Tujuan utama eksperimen ini adalah untuk mengukur kekuatan lekatan. Tatasusun ortogan L_9 digunakan ketika eksperimen dijalankan. Berdasarkan keputusan eksperimen, sekiranya menggunakan daya sebanyak 15N, ketebalan mortar 4mm, bentuk mortar segiempat dan kelajuan getaran motor 2500 rpm akan menghasilkan kekuatan lekatan paling tinggi. Proses rekabentuk dan pembangunan mesin adalah berasaskan kepada proses baru, IDEF3 dan parameter-parameter yang di perolehi dari eksperimen. Pendekatan baru kaedah rekabentuk telah digunakan untuk mengetahui samada proses tersebut sesuai untuk dimekanisasikan. Mesin tersebut telah dibahagikan kepada dua modul iaitu modul penyerak mortar dan modul penentuletak jubin. Mesin tersebut telah berjaya memasang jubin lantai dalam masa 5.94 saat dengan jarak antara jubin 2.46 ± 0.96 mm. Ia adalah tiga kali lebih cepat daripada proses manual dengan kos anggaran kira-kira RM 0.53 per jubin.

DEVELOPMENT OF AUTOMATIC FLOOR TILE LAYING MACHINE

ABSTRACT

Floor tile laying process is a finishing job usually done manually. This process is described in detail including the tile laying work flow, thinset thickness, tiles pattern, tools, tiles installation defects, costs and work rate. A cost analysis of tile laying process was made based on data obtained in one of the construction project in Langkawi in 2005. The labor cost was RM 1.50 per feet square of tiles. The material costs however vary with the quality and design of tiles. A field study was carried out to measure the work rate of manual tile installation where the average rate was 19.2 seconds per tile of 300mm x 300mm. The existing research and robot technology is discussed in this research including the various configurations considered by the researchers. Based on these, important elements of floor tile laying automation were identified as lacks of data on tile laying work itself, manipulator design and costs effectiveness. This research is motivated by the need to reduce the installation time and labor cost while maintaining quality. The manual tile laying process has been successfully constructed in details using IDEF3 process and object schematic. To increase the work rate, the redundant activities have been eliminated and some activities are combined. A new simplified process has been constructed using IDEF3 as a basis for a new mechanized unit which can be more suitable for automation. Experiments are conducted using Taguchi method to determine the optimizing process parameters of adhesion strength between tile and mortar bed. The effects of four process parameters of force, thinset mortar thickness, shape of ribs and vibration motor speed have been explored. The primary response under study is the adhesion strength. An L_9 orthogonal array was used to accommodate the experiments. The study predicted that the highest adhesion strength could be obtained with force of 15N, thinset mortar thickness of 4mm, square-shape of thinset ribs and speed of 2500 rpm for vibration motor. The machine has been designed and developed based on the new process of IDEF3 and parameters obtained from the experiment. The new approach of design method has been used in order to find out either the process is suitable for mechanization. The machine consists of two modules of thinset mortar dispenser and tile setter module. The machine successfully installed tiles at a rate of 5.94 seconds per tile and gap between tiles of 2.46 ± 0.96 mm. This is 3 times faster than manual process with installation costs calculated to be RM 0.53 per tile.

CHAPTER ONE
INTRODUCTION

1.1. Introduction

Construction is one of the many industries important to developing country like Malaysia. There are many challenges and difficulties faced by the industry. Warszawski et al (1998) reported that there are four serious problems in the construction industry today; low labor efficiency, increasing accident rate at construction sites, poor finishing or workmanship and insufficient supply of skilled workers. In Malaysia, construction companies usually employ immigrant workers due to their lower salaries compared to local workforce. In 2001, the International Labor Organization reported that 80% of the entire construction workforce in Malaysia is foreign labor. This scenario causes imbalance of the services account and affects the country's economic system (because of the flow of currency to foreign countries) (Kanapathy, 2004). One of the ways to overcome this is to mechanize or automate some of the manual construction activities.

In Malaysia, one of the finishes normally required in new buildings are the tile installations, such as floor tiles installation in big halls. There are various types of floor tiles which include ceramic tiles, porcelain tiles, granite tiles and quarry tiles and these are installed based on the application and users' requirements. Among the favorite tiles are ceramic tiles because of easy maintenance, heavy duty and reliable (Ridzwan, 2005).

Wan (2004) reported that failure of tiling systems in Malaysia and Singapore has increased over recent years. This is because of lack of understanding of the characteristics and improper use of material, inappropriateness of various systems, poor workmanship, lack of ISO standard and the demands on construction time. Currently, the tile installation process is done manually which require skilled workers.

1.2. Problem Identification and Definition

From the observation of the construction of the Mosque of Syed Sirajuddin Jamalullail in 2005, it took two working days (8 hours per day) to install 187 meter square of tiles by two workers. In average, one worker only covered 93.5 meter square for 16 hours. According to the site engineer, this is because of lack of skilled worker, the long time taken to mix and refill the thinset, human factor such as exhaustion and unexpected problems (Ridzwan, 2005). The factors mentioned above increase the duration of the work.

Figure 1.1 shows the flow chart of the activities in the tile laying process. The chart shows the activities starting from mortar bed setup up to finishing installation and can be categorized into three main phases. These are preparation phase, tile setting phase and grouting phase. The preparation phase involves mortar bed setup, mortar bed leveling, tiles planning and tile preparation. Mortar bed is a mixture of Portland cement, sand and water. The purpose of mortar bed is to create an even and level before laying the tiles. In tile planning, the dimensions of the room are measured and the numbers of tiles needed are determined together with the tiles pattern. The tiles preparation is where the tiles are soaked in water to remove dust or unexpected materials at the back of tiles which can prevent good adhesion.

Tile setting involved spreading thinset mortar, tile setting and tile leveling. Thinset mortar is a mixture of pure Portland cement and water and sometimes adhesive material. There are two spreading thinset mortar techniques. The first is where it is spread at the back of tiles also known as back butter technique and the second is where it is spread direct to mortar bed surface. After thinset spreading, they are combed using notched trowel. When laying the tiles, the gaps between the tiles are controlled using tiles spacer of different types of sizes depending on the size. Subsequently, the tiles are leveled by beating the tiles to the required level. In this phase, the workers carried out three tasks continuously which are spreading thinset mortar, laying the tiles and leveling. Clearly these jobs involve a lot of movement and can be considered as labor intensive.

Grouting is a process to apply filler between the gaps of tiles where the type of filler depends on the use. Waterproof grout is normally used for bathroom or pool floor. The excess filler are removed using wet sponge.

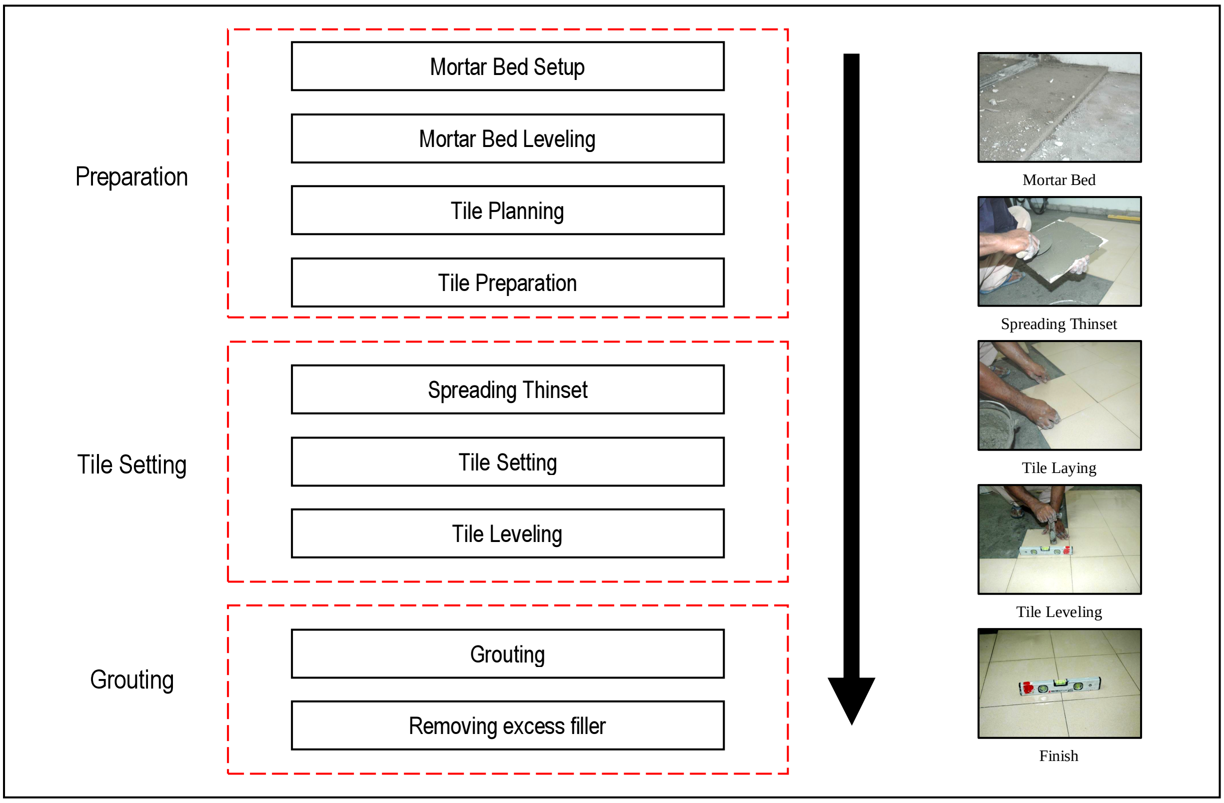

Figure 1.1: Flow chart of tile laying process.

1.3. Problem Statement

Tile laying processes are labor intensive involving repetitive activities, time consuming and requiring skilled workers. To overcome the skilled worker shortage, low productivity, and time consuming the process should be mechanized. The new tile laying machine will be designed and developed to carry out these jobs. The machine can be operated by the unskilled worker.

1.4. Research Objective

The main objectives of the research are;

i. To gather the technical data for development of product on tile laying process. This includes physical properties, optimum parameters of the process and the working rate of existing technique of tile laying process.

ii. To develop a design approach to mechanize and subsequently automate the manual tile laying process.

iii. To design and develop an automatic floor tile laying machine that can complete the task faster than manual process.

1.5. Thesis Layout

This thesis consists of nine chapters. The first chapter is an introduction and gives the general idea for the whole thesis. These include problem identification, definition, problem statement, research objective and layout. Second chapter includes literature reviews which discussed the construction automation issues, tile laying process and existing related technologies. The manual and machine performance and technologies comparison are also discussed in this chapter. The third chapter is a methodology chapter which described the overall research approach. Chapter four described the field study on the existing tile laying process where the manual performance and installation quality are detailed out and discussed. The process mapping and discussion is located in chapter five. This includes the new process which has been simplified to be used in machine development stage. Chapter six explained and discussed the experiments to find out the optimum process parameters. These include the procedure and method used in this experiment. The seventh chapter described approach to design and development of the machine. The machine is developed using a new approach of design method and being discussed in chapter seven. Chapter eight discussed the new machine performance compare to manual work and existing technologies. It also discussed the costs of the machine and labor. The conclusion and future work of this research will be described in chapter nine.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter describes existing technologies in construction automation related to tile laying. Also discusses the factors that should be considered in development of construction automation machine and existing technique of manual tile laying.

2.2 Construction Automation

Research in construction automation and robotics has grown significantly. Countries such as Germany, US and Japan have developed their own robots or machine for construction site usage. The definition of robot by Robotics Industry Association is a reprogrammable multifunctional manipulator designed to move material, parts, tools and specialized devices for the performance of variety task. “Automated” devices may include other manipulators and equipment that follow a fixed sequence or remote controls (Slaughter, 1997).

In Japan, the need of the construction automation is because of three factors which are physically hardworking, hazardous and dirty, and these caused an unattractive job for young people. Meanwhile, poor working conditions and high injury and fatality rates are frequently considered in United State (John and Hiroshi, 1996).

Constructions robot can be divided into four main groups. It is exterior handling robot, horizontal finisher, vertical finisher and interior finisher. Exterior handling robots have configurations like mobile cranes and its function is to handle large loads such as steel bars, prefabricated elements and concrete buckets. Floor surface treatment such as smoothing and trowelling is a task which can be grouped as horizontal finisher robot. Painting or inspecting exterior walls can be categorized as a part of vertical finisher. Interior finishers usually have an anthropomorphic configuration to do a task inside the building such as painting and masonry (Warszawski, 1990). Figure 2.1 below shows the stage of the development of automation construction in several countries carried out in 1997. Slaughter (1997) looked into the five stages of development which include development model, small scale laboratory, full scale laboratory, field tested and finally the commercial product. Japan leads in automation construction with the rate of development of the technologies particularly the commercial stage higher than other countries.

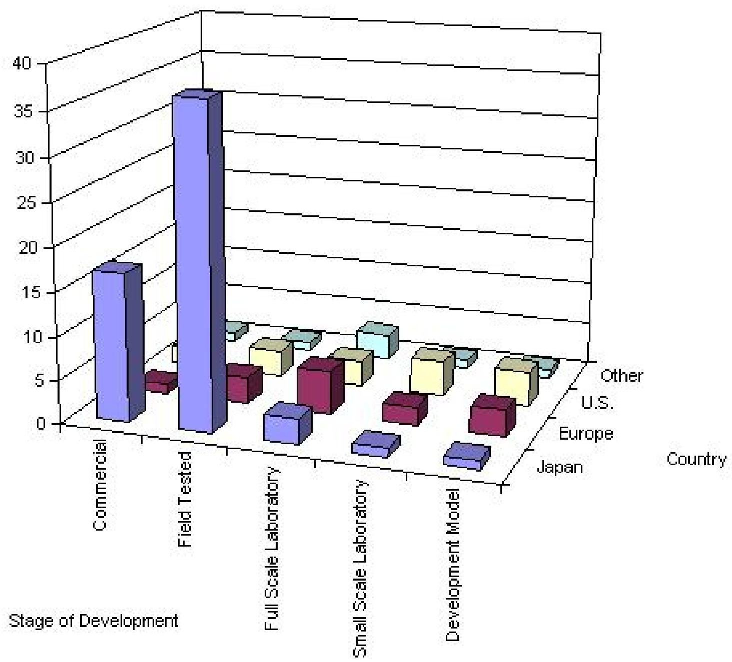

Figure 2.1: Stage of development *(Source: Slaughter, 1997)*

The automation of construction has increased the productivity in construction. Construction Industry Institute (2005) claimed that the application of the automation construction can increase the quality of finishing, improved ability, shorter time required and decrease hazardous faced by workers at construction site. Table 2.1 below shows the productivity improvements that have been realized in concrete screeding.

Table 2.1: Production improvements realized in concrete screeding

Automated Technology	When automated technology is used		Productivity when technology not used
	Set-up and breakdown	Productivity	
Laser Screed	-	34.49 m^2 / hr	10.79 m^2 / hr
	1 hr	100 cy / hr	60 cy / hr
Bidwell (PCC Paver)	2 days	35 cy / hr	10 cy / hr
Ac Paver	5 min	80 tons/hr	60 tons / hr
Mobile Screeding	1-2 days	70 cy / hr	30 cy / hr

Resource: Construction Industry Institute, 2005

From Table 2.1 above, the coverage area of leveled cement screed increase three times or 320% from 10.79 m^2/hr to 34.49 m^2/hr after the laser screed was used. The application of the Bidwell Paver and Ac Paver has increased the productivity which are 350% and 133% although the time taken to setup is 2 days for Bidwell Paver and 5 minutes for Ac Paver. While using mobile screeding, the total cycle per hour has increase 2.3 times compare to 30 cycle per hour before automated technology was used. This data proved the increased productivity attributed to automation of an initially manual process.

2.3 Tile Laying Tools and Material

Mortar bed is normally prepared before laying tiles to obtain a level surface of the floor. The thickness of mortar bed is between 25mm and 50mm. Mortar bed mixture usually consists of 1 part of Portland cement, 5 parts of damp sand and an adequate amount of water (Tile Doctor, 2005). A thinner layer of mortar bed of 18mm can be used depending on the unevenness of the concrete slab (Warmboard, 2005). Figure 2.2 shows mortar bed located on top of a concrete slab and the thinset mortar applied on the mortar bed.

Thinset mortar in general consists of pure Portland cement and water. But, sometimes the thinset mortar can be a combination of sand, Portland cement and an adequate of water or latex (Shaw, 2005). Thinset is specified and tested under ANSI A

118.1 1985 for dry set Portland cement mortar and ANSI A 118.4 1985 for latex modified Portland cement mortar (Tile Doctor, 2005). Usually, floor and countertops used sanded thinset mortar and walls, countertops and fixtures used sanded or unsanded thinset mortar .There are two techniques for spreading thinset mortar; i) spreading thinset mortar at the back of tile also known as “back butter” and ii) spreading thinset mortar over the mortar bed. Applying the thinset at the back of tile can reduce a possibility of air trapped under the tile. This technique was claimed suitable for tiles larger than 200 mm x 200 mm (Floor Transformed, 2005).

Spreading a thinset mortar over the mortar bed or at the back of tile is carried out by using a trowel followed by another run with a notched edge to create a direction of straight line. This is to prevent air entrapment and to maintain a uniform level of the bed setting (Wausau, 2005).

Usually, V-notched trowel is used for unsanded thinset mortar and square-notched trowels for sanded thinset mortar because the square ribs pattern of mortar will make beating in process easier and gives better contact. Square notched trowel gave 50% contact with the tile but v-notched trowel gave 10% initial contact with tile and required more beating in to reach the same coverage like square notched trowel (Super-Tek Products, 2005). Figure 2.3 shows three types of notched trowel normally used when installing tiles.

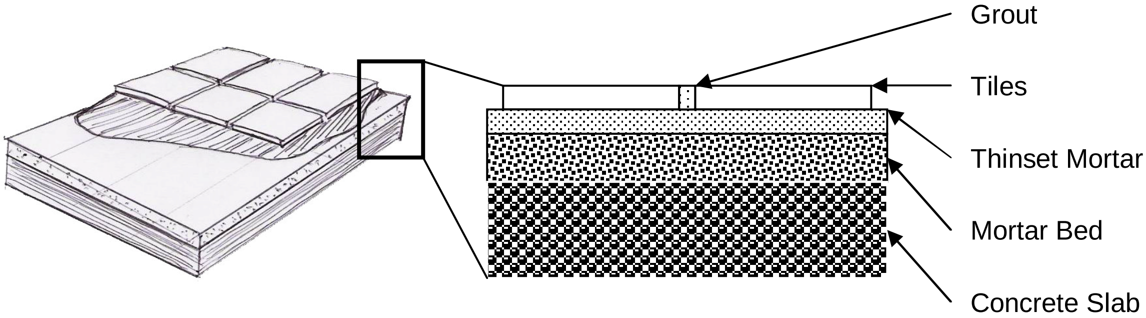

Figure 2.2: Typical commercial tile installation

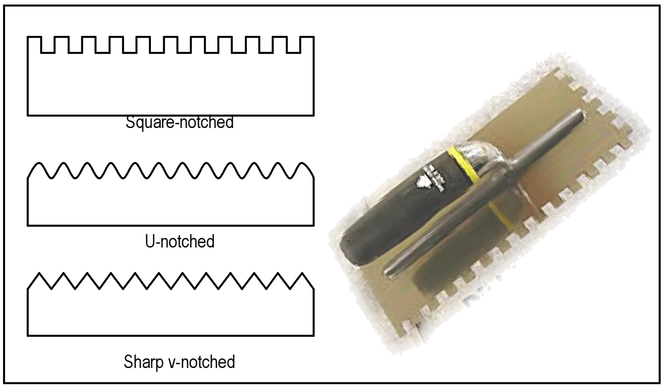

Figure 2.3: Three types of notched trowel.

Figure 2.4 shows a basic pattern for tile laying. Pattern A and C are called “jack-on-jack” pattern and these are the most common pattern and pattern type B and D are known as “running bond” pattern which have an offset grout lines for each row (Lowe’s, 2005).

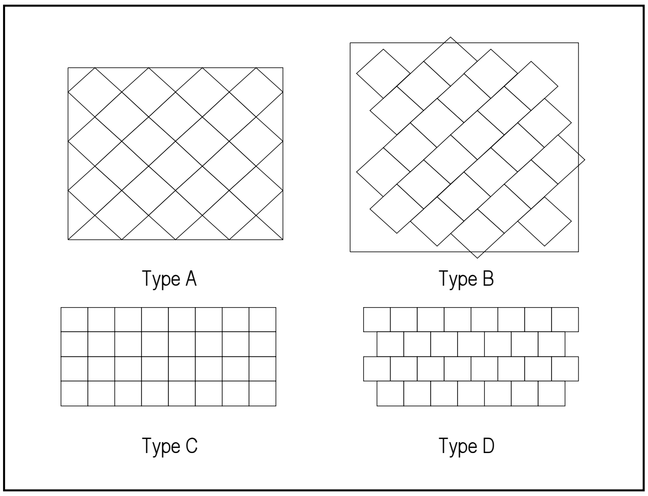

Figure 2.4: Pattern of tile arrangement *(Lowe’s, 2005)*.

Grouting is a process to fill the joint between tiles with cement or filler where excess thinset mortar at the gap between the tiles are first removed and flat edge of trowel is used to lay grout to the surface of the tiles with the gap between tiles fully filled by the grout. The excess grouts from the face of tiles are removed and subsequently the faces of tiles are cleaned with wet clothes (Interceramic, 2005). The gaps between tiles can be made uniform by the use of spacer. Special tool is available with adjustable tile spacing and ensuring grout line uniformity between tiles (Prazi USA, 2005).

2.4 Tile Laying Process

There are several techniques to install the tiles depending on the types of tiles. The process explained here is applicable to ceramic tile. Before laying, the tiles must be soaked in the clean water for 15 to 60 minutes to remove dust and unused material at the back of tiles which can prevent adhesion (Super-Tek, 2005).

Tile laying process can be classified into three phases of preparation, tile setting and grouting. The preparation phase includes mortar bed preparation and leveling, tile planning, checking of tile defect, removing dusts at the back of the tiles, soaking of tiles in water and thinset mortar preparation. Tile setting phase includes spacer setup, spreading thinset mortar, skimming the thinset mortar, laying tiles, leveling and removing excess thinset mortar. After laying the tiles, they must be checked to ensure level and the pattern is uniform. Tile spacer can be used in this process to get uniform spacing of tiles (Tile Doctor, 2005). Grouting should be done after 24 hours laying the tiles (Floors Transformed, 2005). Grouting is done to fill the gap between the tile with a cement or special filler depending on the usage of the tile. If the tiles are installed in the bathroom, special filler can be used in the grouting process (Shaw, 2005). This phase also includes removing excess filler and wiping the tiles with wet sponge for final finishing. Figure 2.5 below shows the summary of tile laying process.

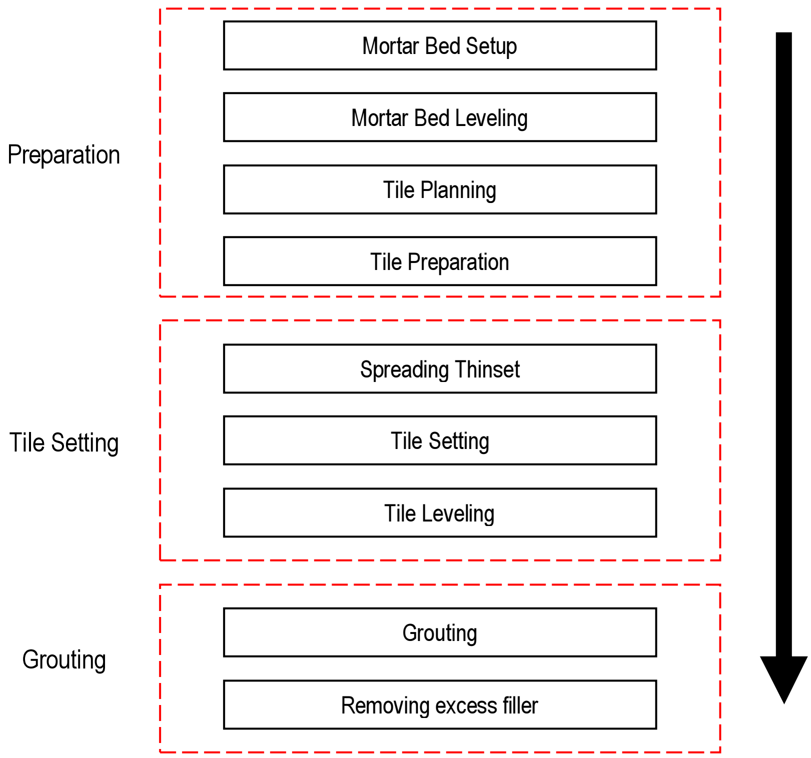

Figure 2.5: Tile laying process schematics.

2.5 Installation Time

Hagen et al. (1996) reported their study on manual tile laying performance and found the total time taken to install a tile is about 24 seconds per tile or 111.5 m^2 per 8 hours for 0.3 x 0.3 m tile. The time includes floor preparation, spreading of adhesive, loading of tiles on trolley and laying down tiles. Table 2.2 shows of the individual process in the tile laying work.

Table 2.2: Manual tile laying performance

Process	Specifics	Time
Floor preparation (sweeping, caulking, etc)	250.8 m^2	45 min
Spreading adhesive	250.8 m^2	120 min
Loading tiles on trolley	8 cartons	15 min
Laying down tiles	360 tiles	48 min

Resource: Hagen et al, 1996

The workers are capable to place 232.2 m^2 to 278.7 m^2 per day with a rate of $26.00 per hours with costs of $2800 to $3400 to install 3716.1 m^2 floors (Hagen et al., 1996).

Navon (2000) reported the work rate to install the tiles for area 3 x 4 meter and tiles of size 0.2 x 0.2 m is 2.13 m^2/h, meanwhile work rate to install the tiles for area 2.6 x 2.6 meter with a tiles size 0.1 x 0.2 m are 0.7 m^2/h When converted to meter square per day the value is 16.9 m^2 per day which is allows for direct comparison with Hagen (1996). The work rates vary because of the size of tiles and the shape of the room.

2.6 Classification of Installation Error

Hagen (1996) classified the tile installation defects into three groups. These are skew, gap and shift. Figure 2.6 below show the defects normally found in tiles installation.

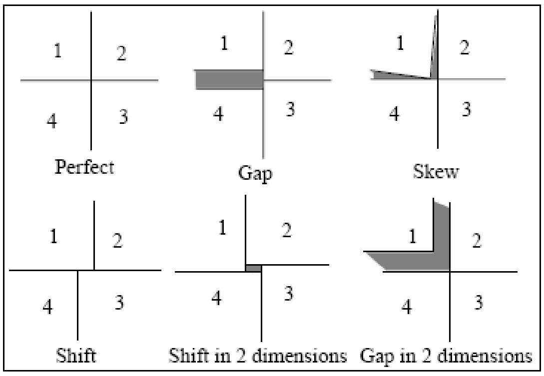

Figure 2.6: Tile laying installation defects. *(Source: Hagen, 1996)*

Gap error occurs when one of the tiles has a major gap with the near tiles. Gap error also can be in two dimensions as shown in figure above. Skew error is a phenomenon when the tile was place slightly angled and not parallel with the near tiles. Shift is an error when the grout line is not cross properly. It is occur when the two tiles (side by side) was slightly move forward or backward. It also can turn out into two dimensions which is created the small hole (square shape) at the cross section.

The installer has to ensure the tiles be set in straight parallel lines and the distances between neighboring tiles must be consistent (Navon, 2000). According to Ridzwan, (2005) the horizontal error is due to poor skills and lack of experience. When the tile is not leveled horizontally, water may collect. Figure 2.7 below shows horizontal defect of tiles installation.

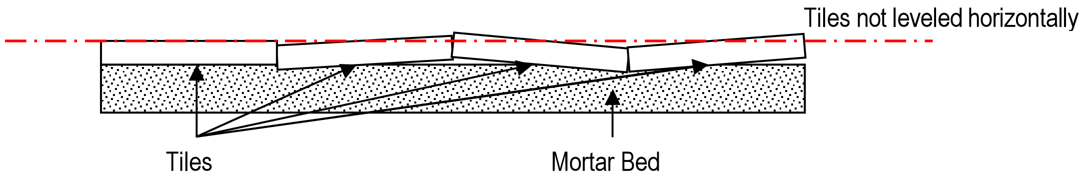

Figure 2.7: Horizontal effects of tiles.

The leveling process was done during the installation process. Some of the installer laying the tiles slightly angled (approximately 0.5~1 degree) to ensure the water can run to the essential location. The reason of this angled level is for cleaning issue.

Poor of workmanship also affected the strength of tile bonding quality. Zhi and Wei (1997) discovered the tile setting pressure, adhesive inner cavity and adhesive open time has a significant to the strength of the bonding quality.

2.7 Tile Laying and Related Automation – State of the art

Currently, tile installation process is done manually and highly dependant on human skills. Until now, there is no commercially available machine or robot to carry out this task but there are already attempts made by researchers to automate this process.

In year 1991, Giorgio and Paolo have discovered the application of robot arm to place the tile. PUMA 562 manipulators robot with 6 degree of freedom has been used as a preliminary investigation to automate placing the tiles on the surface. Equipped with the force/torque wrist sensor, the total force to press the tiles can be controlled. The study was found that the application of robot arm has a potential to automate the tile laying process.

Technion Israel Institute Technology has developed the first full scale prototype of construction finishing robot which is called TAMIR (Technion Autonomous Multipurpose Interior Robot) as shown in figure 2.8 below.

Figure 2.8: Technion Autonomous Multipurpose Interior Robot
(Source: Warszawski and Rosenfeld 1994)

This robot was designed to do three main tasks namely tile setting, painting and wall building. TAMIR consisted of robotic arm with 6 DOF attached on a computer controlled carriage. For tile setting task, the robot was equipped with a vacuum gripper at the end effectors to lift tiles from the cartridge and laid them at precise position on the wall. The arm will gently press the tile against the wall until the thinset mortar reaches the proper thickness. The robot worked fully automatic in the working radius of approximately 1.5 meters (Warszawski and Rosenfeld 1994).

Navon (1995) has proposed a methodology for the development of construction robots and used it to develop an interior finishing robot for horizontal surface (floor) called Surface Horizontal Autonomous Multipurpose Interior Robot, SHAMIR with a work module and mobility module. The work module includes the robot's arm, end effector, sensors and the material supply. SHAMIR was tested using graphic simulation system and in this testing the tile were stored on the robot in cartridges and the operation carried out by a prismatic arm of three degree of freedom. This robot worked in a workstation environment. The robot has to reach the workstation and carry out positioning calibration, subsequently the robot will spray a thinset mortar to the area and the end effector will start laying the tiles. The robot has to carry the material supply system, power supply, propulsion and controller system and resulting in the weight of the robot amounting to 400 kg. From the graphic simulation system results, the productivity was reported to be three times higher than the manual method which is 6 m^2/hours. Figure 2.9 below shows a model of SHAMIR with the graphic simulation system.

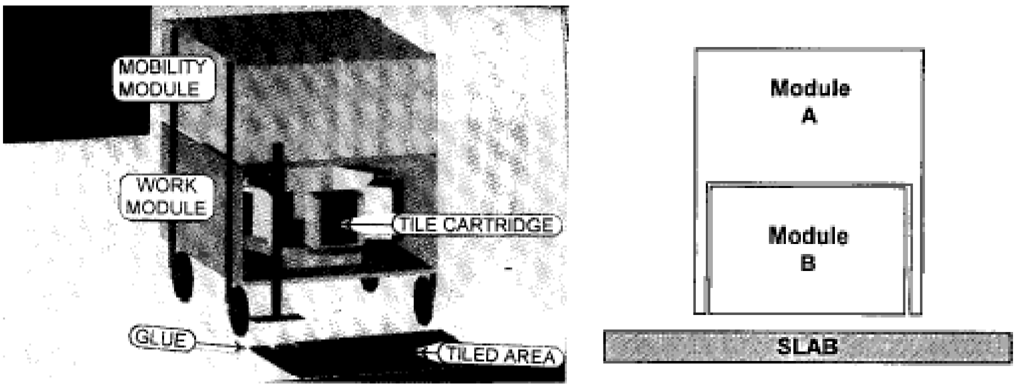

Figure 2.9: SHAMIR with the graphic simulation system.
(Source: Navon, 1995)

Hagen (1996) has come out with a conceptual design of a mobile robot for automatic tile installation and time taken to install each tile were expected to be equal or less than 12 second. The robot process included movement from the previous to the next tile, acquire and process images to determine fine position offset, position tile in contact with ground, lay it down and lastly acquire and process image to ascertain tiles installation quality. They have configured a four wheel vehicle with omni directional motion with stereo camera based sensing to locate tile edges and seams on the floor. Tiles for the robot are fed from a hopper system from the opposite end of the vehicle and supplied via contact friction belts. In order to check the tiles accuracy, robot position and tile pattern, a laser based retroreflective target positioning system was used. Figure 2.10 below shows a conceptual design of mobile robot for automatic tile installation.

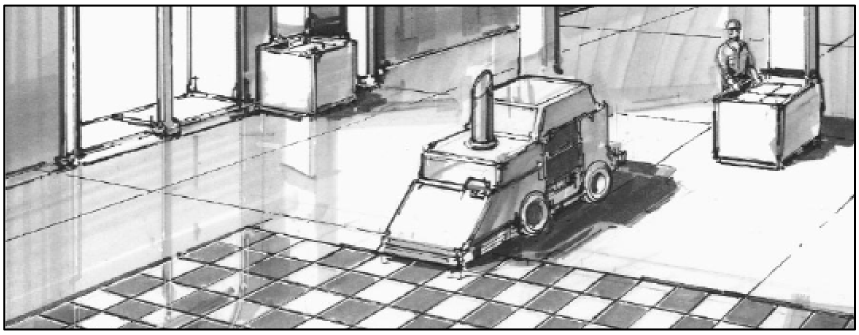

Figure 2.10: Conceptual design of mobile robot for automatic tile installation
(Source: Hagen et al. 1996)

A technology which has an almost similar function with the tiles installation work and has been developed for commercial construction industry use is mobile bricklaying robot. This robot was developed in German and the task of this robot on the construction site are picking bricks or blocks from prepared pallets, apply bonding material to the bricks and placing the bricks with high accuracy and quality. The robot was fully autonomous on the construction site. The prototype called BRONCO (Bricklaying Robot for Use on the Construction Site) has been successfully tested. The tasks include picking a brick from prepared pallet, dropping and calibrating position of bricks, spreading the thinset mortar and placing the bricks with high accuracy position. This robot used vacuum cup to lift the bricks or blocks with a dimension up to 0.625m x 0.36m x 0.250m and weights up to 50kg (Pritschow et. al, 1996). Figure 2.11 below shows the schematic design of mobile bricklaying robot.

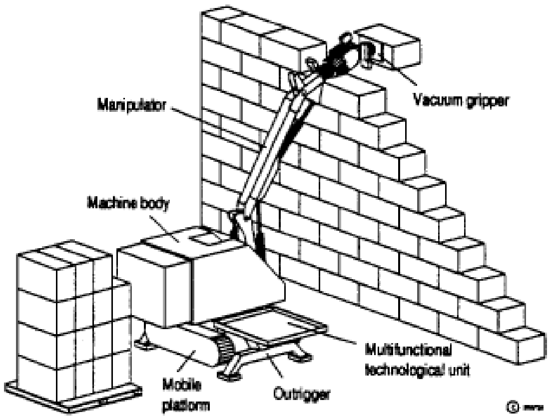

Figure 2.11: Schematic design of complete mobile bricklaying robot.
(Pritschow et al, 1996)

Alan (1996) has developed a mini autonomous tile-laying robot called TileBot. This robot is designed to dispense square tiles according to the program that has been stored in the memory and in the same time avoiding obstacle. This robot was developed with three main functions of tile dispensing, obstacle avoidance and associated with the tile dispenser. Figure 2.12 below shows a vertical stack of tiles and the mechanism to laying tiles. In dispensing system, the robot will dispense fiberglass tiles with 2 x 18 x 38 mm in dimension. A servo motor was used to push out the tiles from vertical stack of about 800 tiles. There are six infrared emitter/detector and six bump sensors installed at the front and back of the vehicle for obstacle avoidance. If the robot detects the obstacle less than 0.254 meter from the vehicle, the system will halt and wait until the obstacle is removed. The infrared sensor has been installed at the tile dispenser to detect the absence of tiles and will halt the system until the dispenser is refilled.

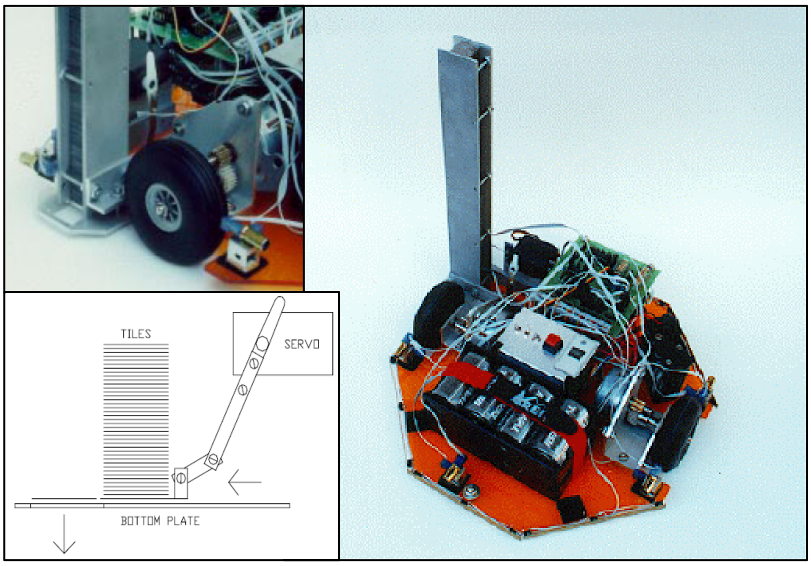

Figure 2.12: Vertical stack of tiles and the mechanism to laying tiles.
(Source: Alan Senior, 1996)

A robot proposed conceptually by Navon has six DOF enabling it to reach all necessary locations, with needed orientation (2000). The robot worked autonomously in the workstation and its movement from existing workstation to other workstation will be done by the operator. The operator also will be doing preparatory work such as loading tile cartridges and completion tasks. From the concept proposed, the robot and the operator worked together as a team. The robot performance has been simulated using graphic simulation as shown in figure 2.13. The simulation results of work rate between $1.6m^2/h$ and $11m^2/h$ were achieved.

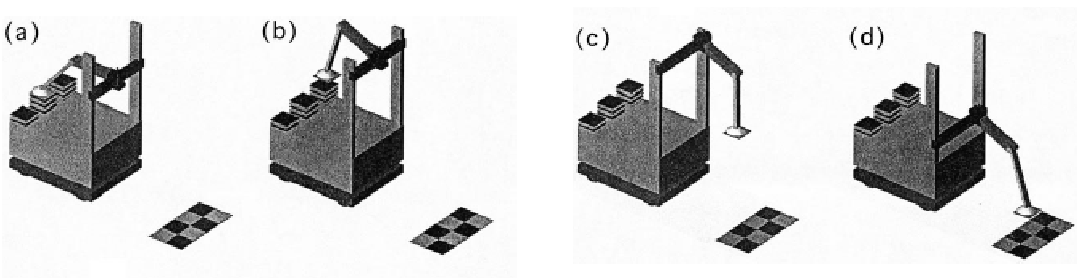

Figure 2.13: Six DOF robots proposed by Navon (2000)

The robot arm picked the tiles from the tiles container which is attached together with the robot body. The tile has been supplied with dry glue at the back. The robot arm will find the correct position to place the tile based on the vision system. After placed the tile, special tools will be used such as microwave or heating system to liquefy the dry glue.

Another related development was a gantry robot with two principle axes of movement controlled by two units of stepper motor. The task of the robot was to pick up small square tiles from a random position and placed it to specific positions depending on the required pattern. Figure 2.14 below shows a robot manipulator and robot manipulator head. The robot used vacuum pick-up cup controlled by switching a small diaphragm pump. To identify the initial position of the tiles, the robot used USB web-camera to capture the images, processes the images and the processor will make a decision for the next move (Bailey et. al, 2001).

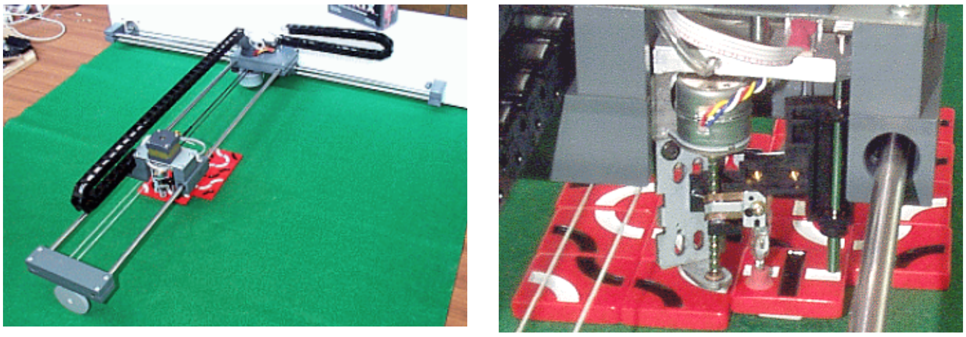

Figure 2.14: Robot manipulator and robot manipulator head.
(Source: Bailey et al. 2001)

A construction robot has to meet several requirements such as high payload, safety, reliability and a wide workspace. These requirements were met by hybrid-type robot (Hyun-seok et al., 2005). The hybrid robot consists of serial and parallel parts. The serial part has wide workspace and low payload and the parallel part has high precision, a narrow workspace and high payload capability. The serial parts used servo motor to control the motion and the parallel parts used pneumatic actuator to control the motion.

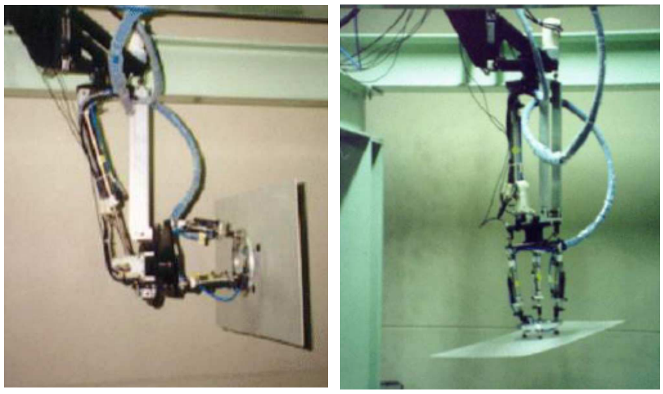

Figure 2.15: Serial-parallel hybrid type robot (Hyeun-Seok Choi et al. 2005)

Figure 2.15 above shows the serial-parallel hybrid type robot. A pneumatic actuator is a strong non-linear system and relatively easy to setup. However, these pneumatic systems are difficult to control especially to control the precision of the movement because of nonlinear dynamic properties such as air compressibility and friction effects. An experimental hybrid robots has been conducted to see the performance of the robot. The task of the robot is to lift and move 5 kg of heavy tile and make a circle path motion in 5 cm diameter. The tile was attached on the end effector with a suction cups. From the experiment, the precision of locating the tiles are less than 3 mm. Hyeun Seok et. al., claimed that even though this robot is not precise, it can be used to support workers for low precision tasks.

2.8 Discussion

Based on the literature reviewed, there is a limited study on the mechanical properties of the thinset mortar. Although the factors affected the bonding strength has been revealed by Zhi and Wei (1997), the optimum parameters for the laying tiles such as types of thinset ribs, force to beat the tiles and thinset thickness has not been reported in literature. To mechanize the tile laying process, these parameters must be known as a guide in designing the machine. These properties are important in the design stage in order to derive the optimum thinset level dispenser.

Before designing the machine, the tile laying process should be mapped in details. Regarding to Bridgewater (1993), the tasks must be contemplated in order to shorten the assembly process. Reducing the number of activities in tile laying process can minimized the time taken to install the tile and the number of parts or component.

Several design and product of automation looked very complicated and difficult to control. Even though from the graphic simulation and field test results showed that automation is better than manual work in term of speed and precision but these machines need specialist knowledge to programmed and control. The existing research on tile laying involved with the applications of robot arm for pick and place, stereo camera for installation quality, laser beam for level purposes and complex algorithm controller.

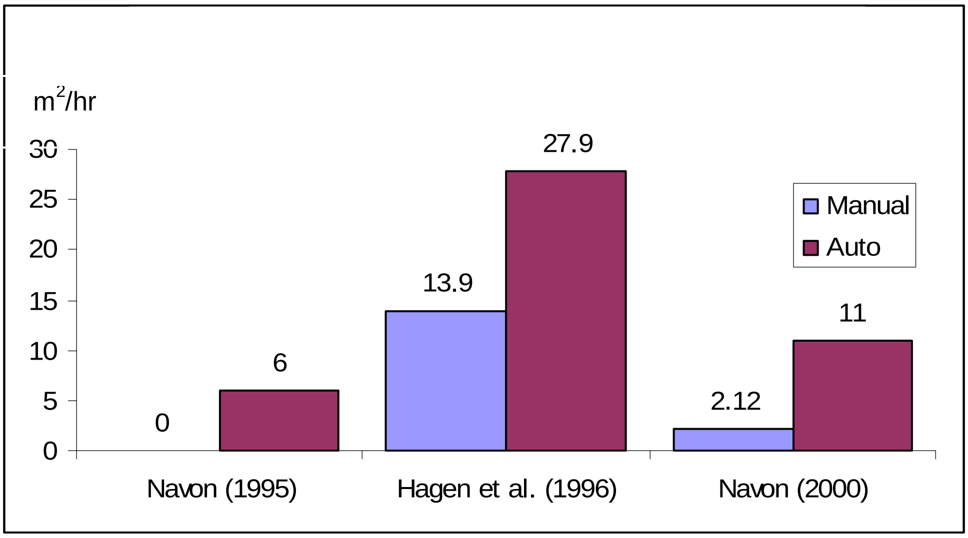

Figure 2.16: A Comparison of manual and automated technology of several tiles laying process performance

Navon (1995) has proposed a conceptual tile laying machine. The result from graphic simulation shows that the work rate of the machine is 6 m^2/hr. Hagen et al (1996) predict the machine can compete the human work rate from 13.9 m^2/hr to 27.9 m^2/hr. Navon (2000) once again revealed the new robot of tile laying and from graphic simulation shows the work rate of the machine is 5.2 times faster than the manual work rate.

The manual work rate varies from one researcher to another researcher as shown by Hagen et al. (1996) and Navon (2000). This may be because of the different sizes of tiles, different pattern arrangement and labor fitness. If the manual work rate release by Hagen et al was used as an indication, the machine proposed by the Navon (2000) is slower and can be considered as not competitive.

The previous researches on automated technology show the applications of complex robot to place the tiles or related tasks. Navon (1995) proposed the prismatic robot arm to handle the tiles from the storage to the location. Hagen et al. (1996) proposed the used of vision system to increase the accuracies of tile placement. Brick laying robot which has been commercialized in Germany used 7 degrees of freedom robot to ensure the robot can maneuver in all direction to place the brick (Pritschow et. al, 1996). Navon (2000) proposed 5 degrees of freedom robot arm to pick and place the tiles. Hyeun-Seok Choi et al. (2005) also proposed the hybrid robot (serial-paralel robot) to place the tile which is too complicated to control and handle. The simplest robot reported by Bailey et al (2001) is gantry robot to pick the tiles from outside and place to the location which was based on two axis gantry for x and y direction where the robot can be easily controlled to arrive at the accurate location to place the tile. Most of the robots used complicated sensors such as laser, robot arm and vision system to ensure the accuracy of tile placement. Giorgio and Paolo (1991) has mentioned in their paper that the application of robot arm needs a large work space for robot to maneuver. The minimum degree of freedom to ensure the end effectors can be oriented in all direction was at least 6 degree of freedom. To maximize the robot arm performance, the robot should be equipped with vision system to identify the correct position.

One similar application which almost all robots above used is suction system. The suction system is used to hold the tile when transferring from storage to the tile location. Easy to control and scratch free are the main reasons why the system was selected.

From the literature, the cost of robots and other technology were not revealed. However based on the tools or technologies which employs the robots requires high investment and not cost competitive. For example, based on the literature (Global Robot Ltd, 2007; Fanuc Robotics, 2007), the cost of robot arm is approximately £12,000. This does not include the mobility unit, stereo camera module and controller. In short, it is very important to ensure that high capital investment and efforts that have been put into research and development in robotics can be materialise thru the full use of robot in construction industry (Warszawski and Navon, 1998).

2.9 Summary

The construction automation has been applied but not in a full scale construction. It has been shown that the application of automated technology has increased the productivity at the construction sites. However, most of the technology used these applications and require high investment. Tile laying processes are repetitive tasks that require some precision measurement. Most of the related research used robot arm as the solution for the pick and place task and to obtain high accuracies of measurement vision systems were used. Some of the important data for the design of tile laying machine is not available such as optimum shape of thinset ribs and thinset mortar thickness.