Future Topics in Manufactured Construction

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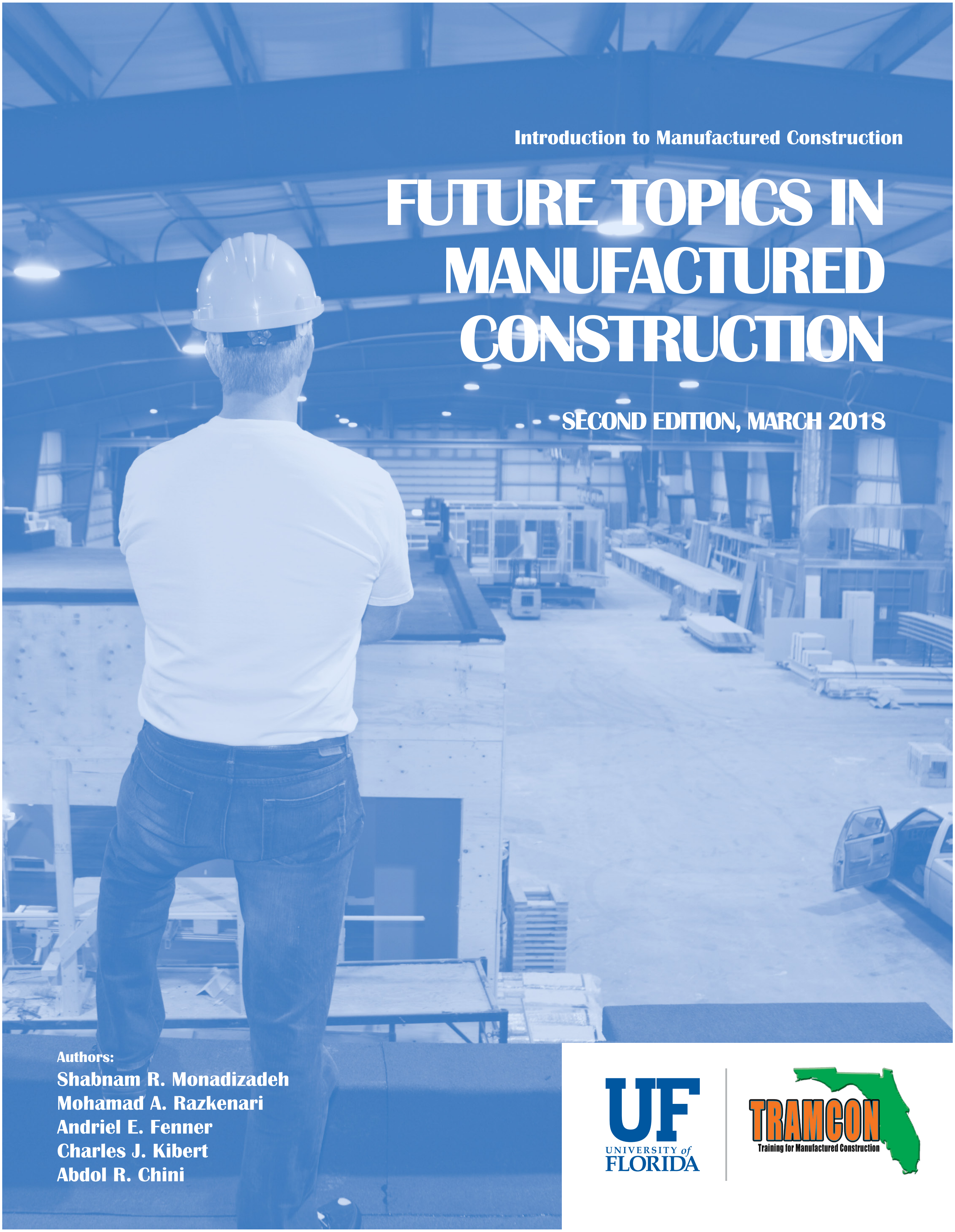

Introduction to Manufactured Construction

FUTURE TOPICS IN MANUFACTURED CONSTRUCTION

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TRAMCON Training for Manufactured Construction

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LEAN STRATEGY AND LEAN CONSTRUCTION

In this final course on Manufactured Construction, we will address future topics that will likely be important for the growth and progress of this industry. Although there are clearly many possible issues that will impact the industry, there are three topics that are most likely to be prime areas of change: Lean construction, and automation and information technologies. Lean construction addresses the efficiency of the manufactured construction process and the use of the most up to date techniques for eliminating waste, speeding production, and developing a well-trained workforce. Finally, it is very likely that the industry will have to adopt the widespread use of computer controlled machine tools, 3D printers, laser cutters, and robotics, all connected to the computer-aided design and manufacturing (CAD/CAM) systems and Building Information Modeling (BIM) design software. High speed networks linking the factory with the logistics system that supplies the materials and products needed in the manufactured construction process are likely to be adopted as part of the shift to advanced technologies. As a result of taking this course, you will be better prepared for the future and also be prepared for future transformative changes.

1.1 INTRODUCTION

In today's highly competitive market, efficiency is an important factor for turning a company into a successful enterprise, or, in business terms, making it profitable. In this age, it is becoming the norm that the customer demands a high quality and defect free product that is delivered fast and is affordable. To accomplish this goal, a company has to look closely at every planning detail and action that increases productivity by eliminating any activity that does not add additional value to the process. This kind of **value-adding approach**, referred here as **lean thinking**, must be achieved by a holistic overall approach rather than through a fragmentary fix.

In this module, we review lean manufacturing concepts used in other manufacturing industries, specifically the automobile industry and learn what methods they use to increase their productivity. We also introduce many Japanese terms to describe the lean manufacturing concepts because many of the fundamental ideas were initiated by the Japanese Toyota Production System. Apart from addressing the origins of the concepts, it's also very helpful to look at the manufacturing systems from another perspective and through visualization methods. The unfamiliar-sounding words that make up the "lean" lexicon help us to remember the very basics of their creators' thoughts.

The ultimate desired outcomes of lean manufacturing are:

- To reduce waste in the supply chain.
- To reduce inventory, and floor space requirements.
- To improve the process by flexible layouts for item-specific outcomes.
- To reduce the production time.
- To meet the expected delivery schedule.

1.1.1 HISTORY AND DEVELOPMENT OF SYSTEMATIC MANUFACTURED PRODUCTION

One of the oldest and earliest large-scale industrial enterprises in the history of manufactured production was the Venetian Arsenal Navy built around 1104 with 16,000 workers, the largest industrial complex that produced the maritime trading vessels in Europe. The area of this industrial complex was about 110 acres or 15 percent of Venice, and it was walled and protected from the public. Different parts of this area were designated to building various, prefabricated ship parts. After the components were ready, it took only one day to build a complete naval ship which was then put into the water and shipped to its destination.

In 1799, an efficient manufacturing production process was initiated by Eli Whitney, the inventor of the cotton gin, who introduced the concept of "interchangeable parts". Through a contract with the US Army, he managed to produce 10,000 muskets at a very low price. After 100 years of engineering development, around 1900, Frederick Taylor founded the idea of "scientific management" in which the initial time-study and the standardized work culture were first launched. Also, around that time, along with Frank Gilbreth who introduced "motion study" and the "process charting", Lillian Gilbreth brought the area of psychology into the planning process. Mrs. Gilbreth was the first to observe, consider and encourage the motivation and attitude of the workers.

In 1910, Henry Ford and his assistant Charles Sorensen created the early version of Just-in-Time (JIT) and lean management. They planned all of the elements of the production system including the workers, machines, products, and tooling, and arranged them into a continuous flowing system to produce the model T automobile (Figure 1.1).

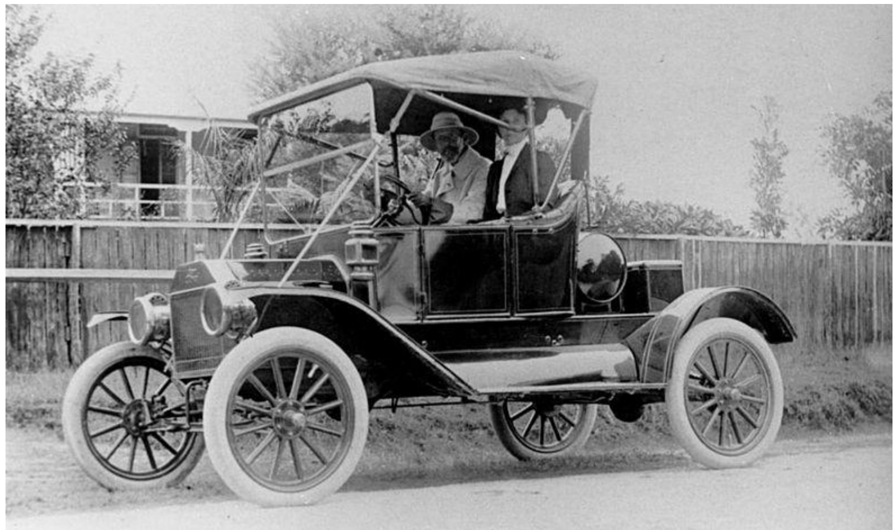


Figure 1.1 Doctor and Mrs. David Hardie in their Model T Ford automobile, ca. 1913
Source: Wikimedia

Ford's flow and inventory system was quite successful, but what was lacking was the flexibility to offer variety. There was only one version of the model T automobile that was continuously produced until 1926 with no changes in models. The machinery was not flexible and produced parts, each having a single number. Starting in 1930, Kiichiro Toyoda, Ohno Taiichi, and Shigeo Shingo began to adopt Ford's manufacturing system and developed it further into what was later called the **Toyota Production System (TPS)** (Figure 1.2). What was added to the known production system of the time was to eliminate the shortcomings of the Ford system and to introduce a new system that was considering the workers as valuable team members. Also, they introduced flexibility into the machinery and tooling to produce a variety of products in a stockless production environment and with a continuous production flow. The outcome of TPS was lower cost, more product variety, higher quality, and faster production.

TPS's concept was then imported back to the west and had been given many names: World Class Manuacturing (WCM), Stockless Production, Continuous Flow Manufacturing (CFM), or simply Toyota Producion. Further contributions of writers such as Richard Schonburger, Robert Hall, and Norman Bodek have been extensively written on the subject matter created the lean concepts that we now know of. After James Womack wrote a book in 1990 on the subject of the automobile industry, "The Machine that Changed the World", a new phrase was born: Lean Manufacturing.

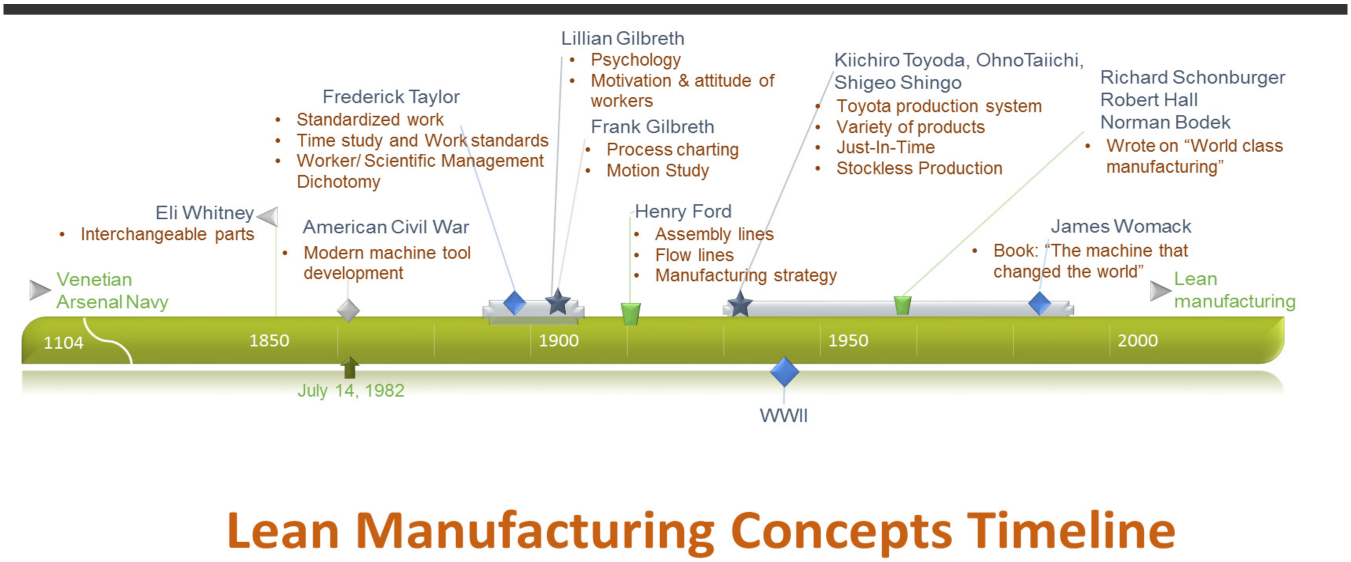


Figure 1.2 Timeline showing the key people who introduced the initial idea of lean process and the related breakthrough in the manufactured Construction industry

1.1.2 ELIMINATING WASTE

Waste in production is the unnecessary activity that uses up valuable resources such as time, material and therefore money and adds no value to the customer. By planning ahead in the manufactured production process, the unwanted waste can be minimized (Figure 1.3).

Seven known types of wastes:

1) **Over-production:** When production is more than the initial customer demand, there is waste.
2) **Over-processing:** Adding more value to what is not needed by the costumer is waste.
3) **Inventory:** Too many/much material or information needed for the process is waste.
4) **Transportation:** The movement of the work through long distances between areas or offices is waste.
5) **Waiting:** Delay on the step between a finished task and the beginning of a new task is waste.
6) **Defects:** Errors and mistakes that must be inspected and fixed are waste.
7) **Motion:** The walking and movement of the people or equipment more than it is required is waste.

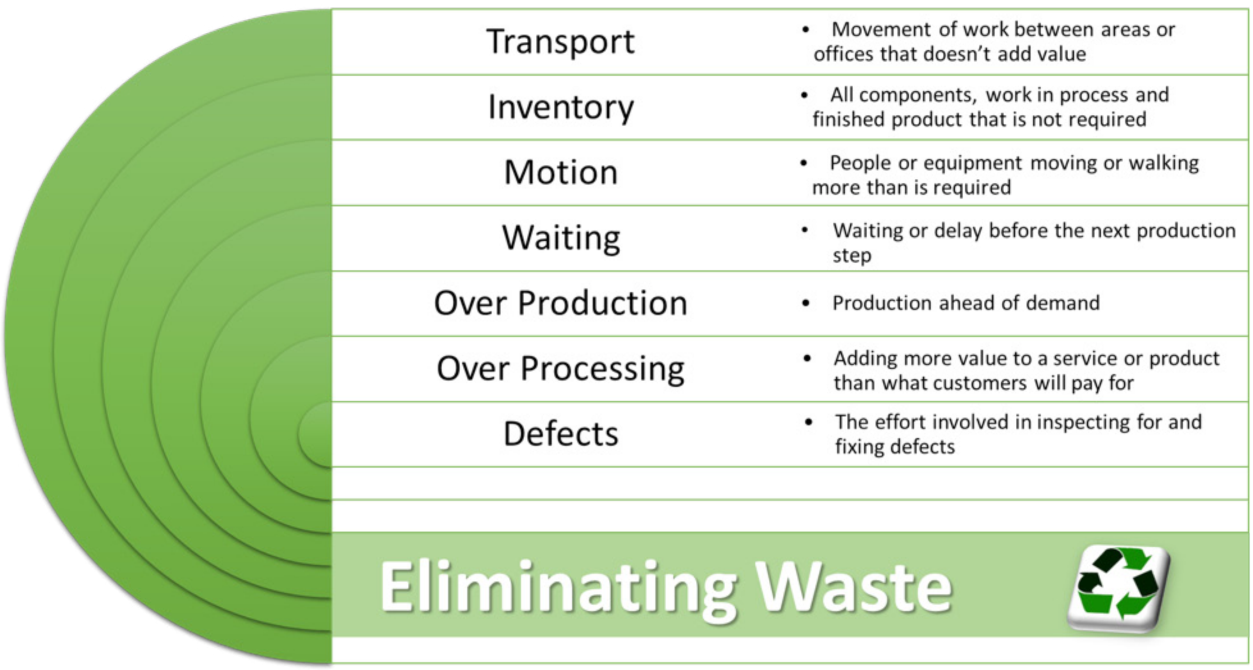


Figure 1.3 To minimize the waste, thinking and planning is necessary. The seven typical waste factors can be eliminated by first recognizing them followed by implementing a strategy to eliminate them.

QUESTION SET 1.1

1) What are the desired outcomes of lean manufacturing?
2) By looking at the lean manufacturing concepts timeline, what conceptual breakthroughs can you find in terms of thinking lean in manufacturing?
3) Define and explain the seven types of waste in the production process.

1.2
LEAN AND MANUFACTURED CONSTRUCTION

Before looking at lean philosophy and tools, we introduce how lean can increase and sustain manufactured construction productivity. This is possible by looking at the manufactured construction process and finding the value-added activities and eliminating waste or non-value-adding elements from the process. We have to realize that the lean methodology is a holistic approach and not just sets of rules that may fix parts of the system. The basic lean principles of valuing customer input, waste reduction and pursuing perfection or quality can be applied in the three phases of design, procurement and production.

Some of the steps for creating a lean work place are to:

- Identify waste
- Eliminate waste
- Standardize processes and plant lay-out
- Value stream planning
- Team culture
- Worker empowerment
- Management commitment
- Error proofing
- Involve the client
- Permanently improve
- Movement and synchronized flow
- Parallel ordering
- Solving constraints
- Inventory and delivery improvement
- Visual management

A very useful tool for achieving lean results is **value-stream-planning**. Here, the planner identifies the waste and the required shop floor standardization to reduce the total cycle time. Cycle time is the time duration of the process, inspection, wait, and movement of the activities. The main objective of this exercise is to add value, reduce production time, and increase the productivity and quality rate (Tabel 1).

Examples of common errors in a manufactured construction plant are due to jigs and fixtures, metal forms (precast concrete), errors in communicating the exact location of a component in the assembly line, errors in welding, layout fixtures, and quality inspections after each process.

Standardization can be achieved by emphasizing repetition to produce standard products as distinguished from regular craft pieces. Logistics planning, storage, and movement of objects can be standardized. Through bar codes and RFI tags (Ready for Installation) units can be identified and tracked, facilitating the overall logistic efforts.

Inventory and delivery of the parts should be optimized so no double-handling occurs, and more freed up space is available. This is called JIT or Just-in-Time delivery where the parts are being delivered based on the client's demand.

Implementing lean culture among personnel and balancing the crew quantity and placement allows for healthy team cooperation and a smooth synchronized work flow. Creating a buffer zone to prevent interference between teams helps produce a conflict-free work environment.

By visual management, team members can communicate more effectively about costs, quality and schedules, traffic regulation, lay out of tasks and work zones. The purpose of visual management is to improve the effectiveness of communication through visual signs and other aids.

? QUESTION SET 1.2

1) Name a few methods that increase and sustain manufactured construction productivity.
2) What is a visual management and communication system in a production plant.

1.3
APPLYING LEAN CONCEPTS TO MANUFACTURED CONSTRUCTION

By using lean methods, we can easily apply lean concepts and lean philosophy to an existing manufactured housing construction production process. The right tool for searching and tackling the problems of production flow is Value-Stream-Mapping. We can create a checklist indicating all activities, resources, durations and related costs associated with that activity. After defining each and every component, we can start to reduce, substitute, and parallel plan the parts to create a better and more efficient production flow.

Table 1 Identifying and defining each activity, and analyzing each activity can help to identify the wasted time that does not add value to the manufacturing process

Activity	No. of Operators	Total Time at Activity	Waste Classification	Waste Classification Time	Value Added	Nonvalue Added	Total Lean Time
Name of Activity	# of operators	Duration A	Material Positioning	Waste of A	Duration A Waste A	Yes	Total A
	# of operators	Duration B	Waiting	Waste of B	Duration B Waste B	No	Total B
	# of operators	Duration C	Transport	Waste of C	Duration C Waste C	Yes	Total C
	# of operators	Duration D	Motion	Waste of D	Duration D Waste D	No	Total D

? QUESTION SET 1.3

1) How do you think creating a checklist can help to identify deficiencies in the production process?
2) What is the difference between a value-added item and a non-value-added item?

1.4
PHILOSOPHY OF THINKING LEAN

1.4.1 CUSTOMER FIRST THINKING

In lean thinking, customers always come first. Customer demands, when he/she wants it, what quantity he/she needs, and what final cost he/she is willing to pay set the boundaries of the production process. Moreover, anybody has to be considered to be a potential customer. The customer is not just the end-user but can be a purchasing agent in an entity, or a connection to a different kind of value adding process.

1.4.2 RESPECT FOR PEOPLE

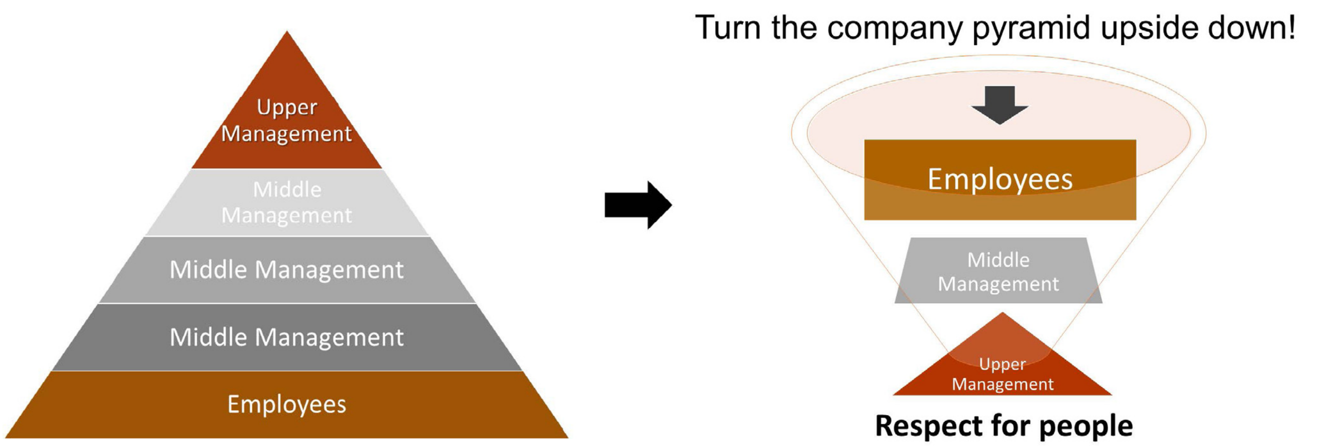


Figure 1.4 In the lean philosophy, the conventional pyramid of work structure is inverted in a way that the employees and the quality of the work they deliver becomes an integral part of the company's success.

In lean philosophy, employees are the most valuable resources rather than machinery (Figure 1.4). By nature, people are more flexible and they can solve the problems at hand. Training at every level, encouraging employee empowerment and management commitment ensures that there is a respectful and trustful culture among the employees and the management. In lean philosophy, the conventional pyramid of the work structure is inverted in a way that the employees and the quality of the work they deliver become integral parts of the company's success. Management focuses on creating a challenging and fulfilling task schedule for the employees, safety at work, job security and creating added-value tasks versus simply crowded or busy workload.

"FIRST WE BUILD PEOPLE , THEN WE BUILD CARS."

Fujo Oho
Former Chairman
Toyota Motor
Corporation

1.4.3 ROLE OF MANAGEMENT

In a lean system, management motivates and leads people, not through the practice of power, but rather by setting up an example by understanding and helping others to achieve a common goal. This is most apparent through a flat management system where the layers of the pyramid structure are fewer and it is easier to communicate with others and make instant decisions. A manager can make a better decision if he/she knows what the exact problem is, how to solve it, how to add value, how to move in synchronization with all layers of management and staff, how to learn from mistakes, and how to reduce waste and defects, resulting in increased product quality.

Gemba walk and the involvement of management

Genci Genbutsu translated from Japanese means “go and see” which in English is pronounced as “Getcha boots on” (Figure 1.5). In TPS, it is customary for managers to go to the source of the problem to understand and take action. The term “Gemba” means real place and was created by Taiichi Ohno to encourage the management to be more involved. The concept of Genci Genbutsu and the Gemba walk is to encourage the management to go where the action takes place and see the problems firsthand on the production line rather than sitting in the office and making decisions based on theories and assumptions. This is the essence of the Gemba walk.

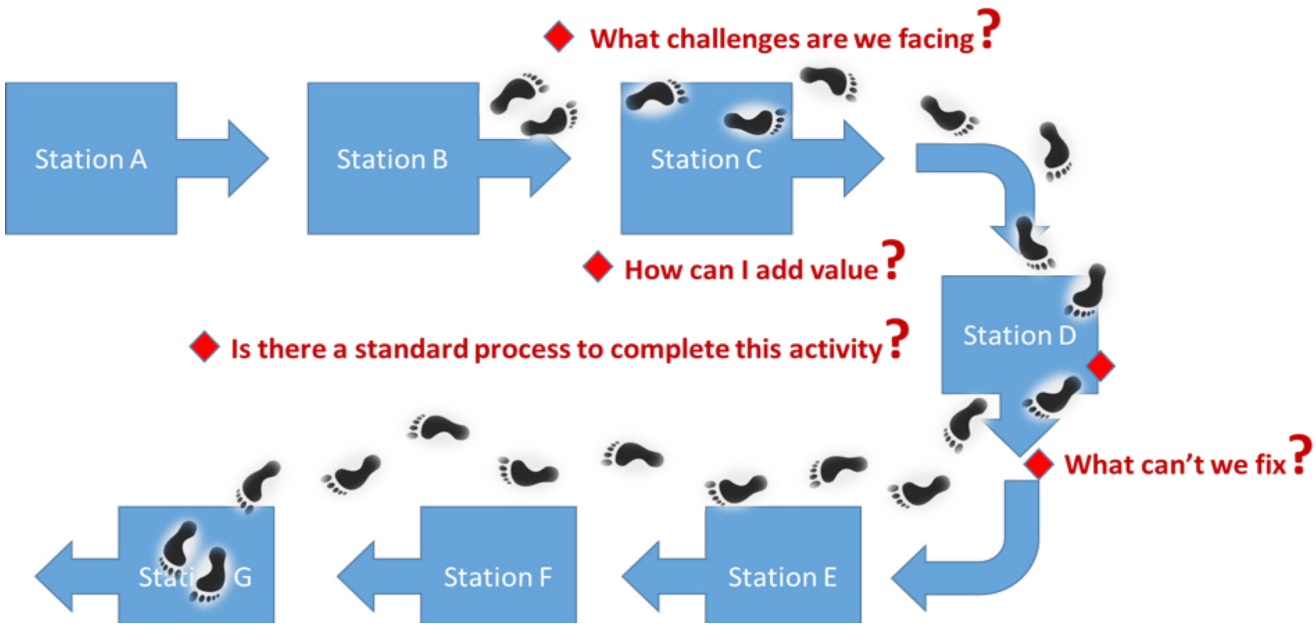


Figure 1.5 “Gemba” walk is a great way for managers to leave the office and be in the middle of action, finding the imperfections and errors and improve the process at hand.

1.4.4 KAIZEN OR INCREMENTAL IMPROVEMENT

Another important concept that was introduced by the Japanese thinkers is **Kaizen**, which translated from Japanese means “lots of small improvements”. The idea of Kaizen is that all small and easy implementing ideas from employees are welcome. By adding the many small improvements, a large collective change is generated. This motivates the employees and make them feel proud since they have the power to make a contribution.

1.4.5 FOCUS ON VALUE-ADDED ACTIVITY

Specify values:
For example “time” and its related queuing duration as a value that can be identified and studied (Figure 1.6).

Map the stream: Map the timing stream that is needed for all actions in a process.
Create flow and eliminate waste: By looking at the big picture, waiting and wasted time can be recognized and eliminated.
Respond to customer pull: The timing plan has to be precisely designed to meet the customer needs and nothing else.
Pursue perfection: Check the quality of the time reduction plan and check it is being followed.

1.4.6 MOVING FORWARD TOGETHER

In a holistic approach, all members perform a function to achieve a common goal, but based on their position, each sees the process through different glasses and has a different micro or macro perspective for achieving the same result (Table 2).

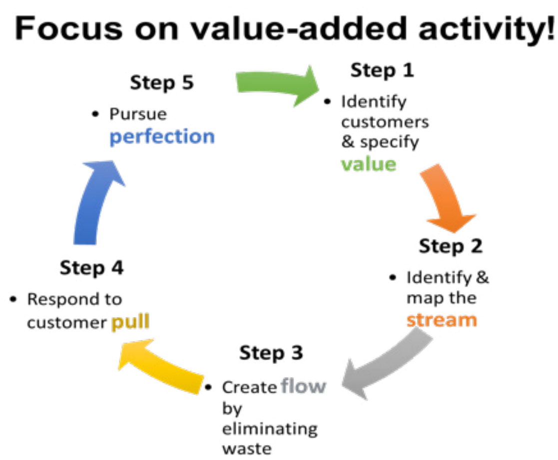


Figure 1.6 Value-added activity eliminates waste and improves productivity.

Table 2 Scope and methods of involvement within various levels of management positions.

Position	Scope	Method
President	Overall big picture Goals of the organization	Philosophical approach
Vice President	Measures of the goals to be accomplished	Policy making
Manager	Missions using strategies designed to realize the goals	Implementation
Supervisor	Specifying roles and actions of team members	Strategy
Team Member	Duties to be completed and roles to be enacted	Tactical approach

1.4.7 IMPORTANT ASPECTS OF LEARNING FROM FAILURE

- Confronting failure rather than ignoring or escaping the problem is a great teacher in the long-term.
- Respect your team members and engage them in problem-solving after a failure has taken place.
- If you do not have enough information, trust your instincts and make decisions.
- Don't blame others, rather identify the mistake and use it as a second chance.
- Set an example through your leadership and strategies when confronting failure and moving your organization toward perfection.

1.4.8 SIX SIGMA

Six Sigma and **lean manufacturing** are toolkits for reducing waste in a business process. Both, Six Sigma and lean manufacturing, are concepts that help to save financial resources. The Six Sigma concept was developed by Bill Smith and Bob Galvin of the Motorola Company in 1989 and is based on the science of statistics, engineering and business (Figure 1.7). The idea behind this model is to reduce defects in production, sales, marketing, design, administration and services to almost zero. "Sigma" is a statistical term referring to the deviation from standard (precisely 3.4 deviation possibility in a million observations). The objective of the process is to reduce output variations so that there is no more than 3.4 defects per million observations.

The steps for improving the productive opportunities in a business are referred to as DMAIC:

Define Opportunity

Measure Performance

Analyze opportunity

Improve performance

Control performance

Lean-Six-Sigma combines the philosophy of Lean with the methodology of Six-Sigma.

Figure 1.7 Six Sigma is a model that reduces defects in all disciplines of production, sales, marketing, design, administration and services to almost zero.

QUESTION SET 1.4

1) "In lean thinking, customers always come first." Explain this statement.
2) How is the work structure pyramid perceived in a lean thinking philosophy?
3) If you are in a management position, how do you improve production on the factory floor?
4) Is incremental improvement effective? Why?
5) Name one "value" that can be identified and studied in a manufacturing process to create a smoother production flow.
6) How should you deal with failure?
7) How does Six Sigma reduce waste in a business process?
8) What does DMAIC stand for?

1.5 TOOLS AND METHODS

The tools and methods of lean manufacturing aim at managing the daily production system as efficiently as possible. In this section, a few of these terms, such as value stream mapping, 5-S house-keeping, Ishikawa Diagram, and other lean-related methods are briefly introduced.

1.5.1 VALUE STREAM MAPPING

Value stream mapping is a comprehensive analytical tool for depicting all the facts to maximize the lean benefits of the whole production process (Figure 1.8). Usually, the analysis starts with a "before-state map" and is improved in all of the areas to create an "after-value-stream map". The components on the map includes people, actions or processes, process timing, wait time, flow of information, flow of material, transportation, and an inventory and the quality of materials.

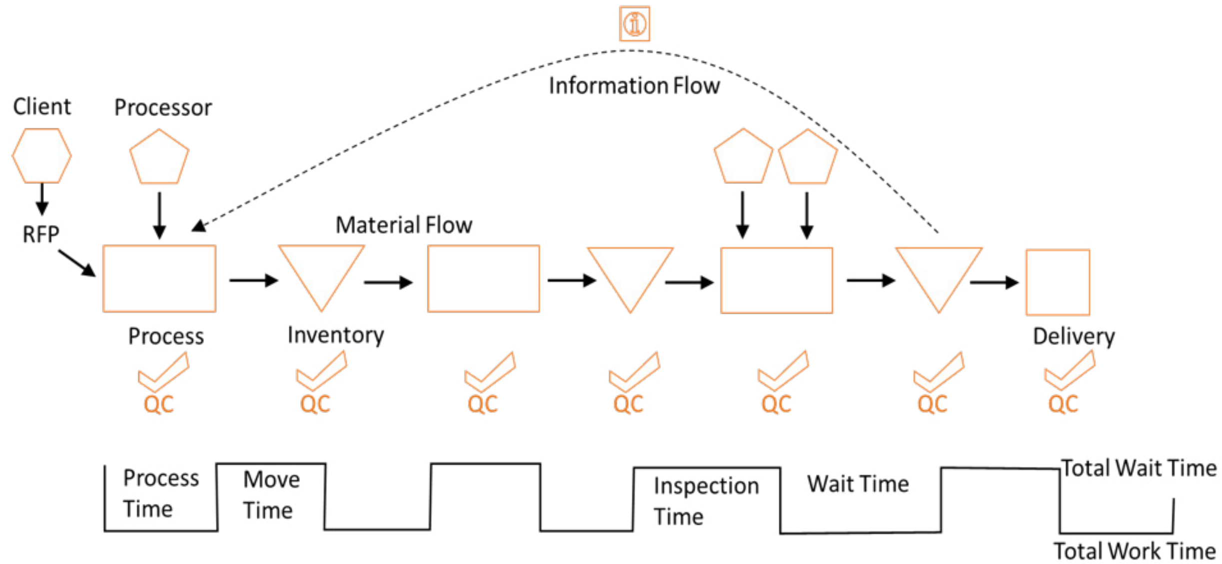


Figure 1.8 In value stream mapping, there are different components that need to be recognized. The map should include people, actions or processes, process timing, wait time, flow of information, flow of materials, transportation, and an inventory of materials.

1.5.2 FIVE-S HOUSEKEEPING

There are 5 Japanese words all beginning with S that explain how the house-keeping of the work space can be improved. In a clean and organized environment, tools are found easily and problems are spotted faster (Figure 1.9).

To create a clean and organized work space:

1) **Sort** (Omit anything that is not needed in the production process)
2) **Set in order** (Organize the items needed)
3) **Shine** (Clean the work area and inspect everything)
4) **Standardize** (Create standards as rules for the above items)
5) **Sustain** (Make sure that the rules are followed)

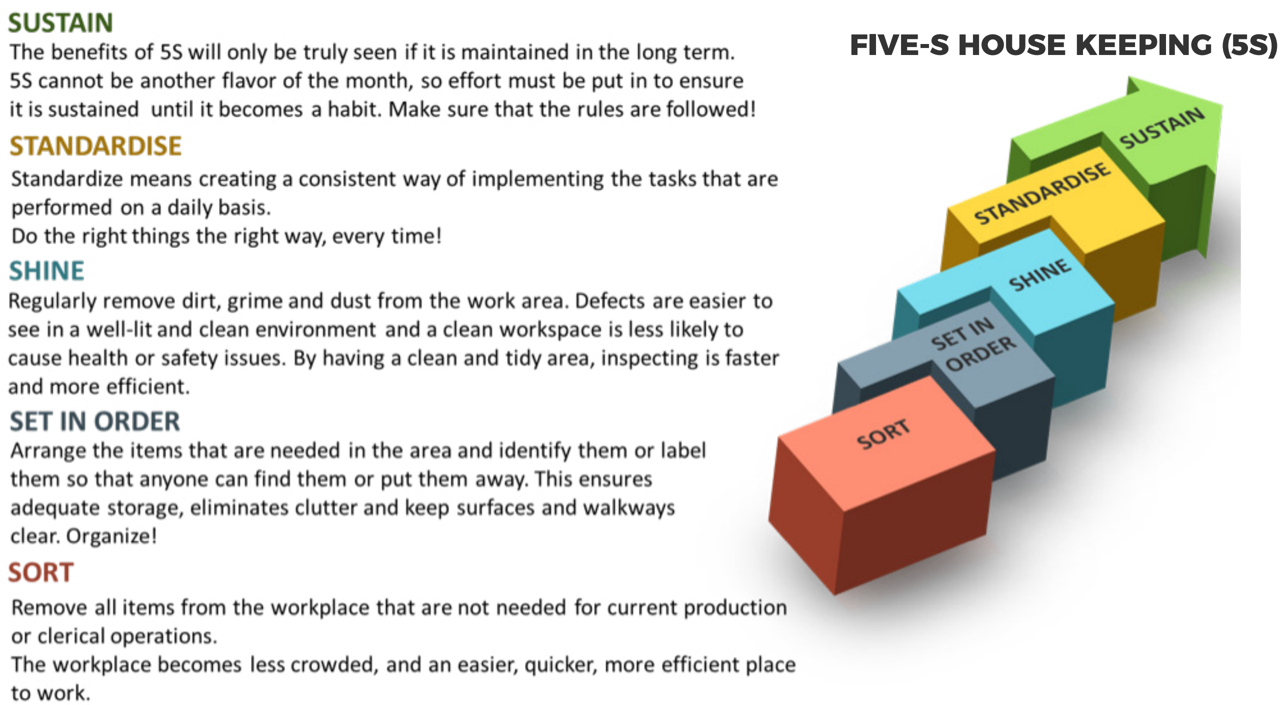


Figure 1.9 Five-S housekeeping helps maintain order, and a place where all tools and parts are found easily.

1.5.3 ISHIKAWA DIAGRAM

The **Ishikawa diagram** is also called the "fish-bone" or "cause and effect" diagram (Figure 1.10). This is a visualization tool for identifying problems and root causes. The potential causes of a problem may be in 6 categories: people, process, equipment, materials, environment, and management.

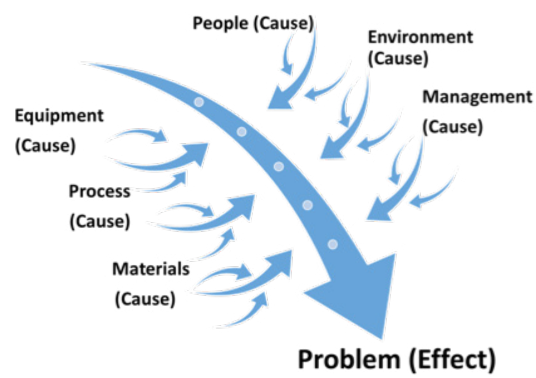
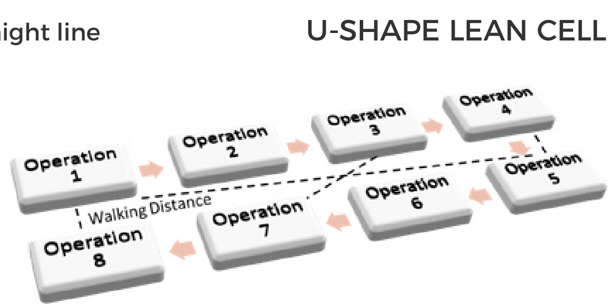


Figure 1.10 The fish-bone diagram assists the processor to target the real cause and solve the problem at hand through the process.

1.5.4 CELLULAR MANUFACTURING

To establishing a highly efficient production flow, the manufacturing must be divided into single processes called works cells. Cellular manufacturing, which groups components by shape and by size, is the key for increasing productivity, a smooth flow, and high quality (Figure 1.11). Some of the design principles for creating optimum cellular performance are as follows:

- Plan small movements among the cells, machines, and operators
- Plan minimal reaching distances for the operators
- Eliminate double-handling
- Plan a u-shaped cell configuration which is better than straight line
- Remember that human ergonomics is not linear



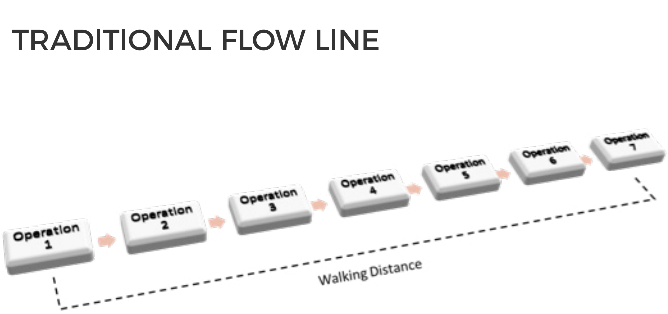


Figure 1.11 U-shaped cell configuration is better than the straight line because it cuts the walking distances that would waste time and resources.

1.5.5 SINGLE MINUTE EXCHANGE OF DIE: HEIJUNKA (LEVEL LOADING)

Heijunka translated from Japanese means level loading. In this method the concentrated production load is leveled out and the lead and the set-up time are minimized up to 50%. By leveling out the fluctuations, a smooth flow will be achieved.

Single Minute Exchange of Die (SMED)
The term **SMED (single-minute-exchange-of-dies)** was introduced by Shigero Shingo and refers to the time lost within the changeover process on large machines. A "die" is a tool used in manufacturing to cut or shape materials mostly using press. This tool defines the actual situation and divides and classifies the process as an integral or external time function and minimizes the time involved by changing the order of the two. Integral activities require that the machines are stopped; for example the removal of guards from the equipment. External activities do not require machinery and can be done when the equipment is running, for example, returning the old tooling and fetching new ones. So, when a machine is running the operator can use the time to obtain new tools (Figure 1.12).

SMED is a system for reducing time required for changeover of the machinery. The name SMED comes from the goal of reducing the changeover time to one-digit minute by changing the steps to “external” when the equipment is running. For example, changing a tire that usually takes 15 minutes to change can be reduced to 15 seconds. This goal is achieved by identifying the tasks as internal or external elements. The strategy is to make as many elements external as possible to simplifying them.

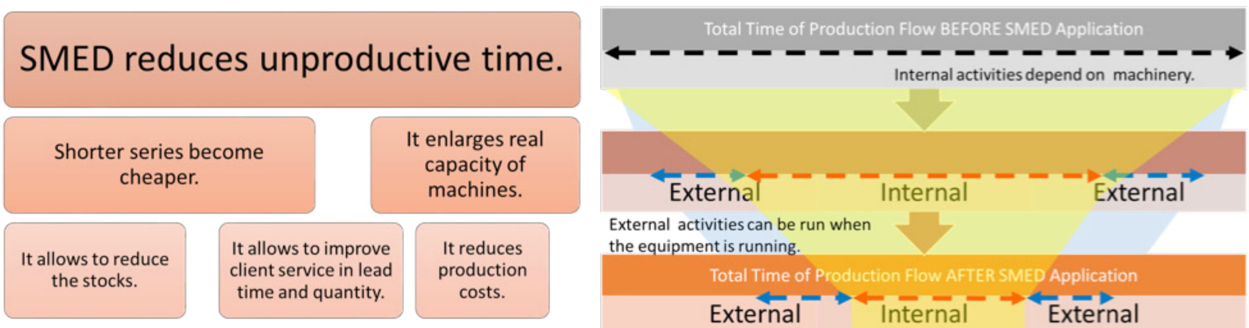


Figure 1.12 SMED reduces the changeover time to one-digit minute through dividing the actions into two groups of “internal” and “external” when the equipment is running.

1.5.6 TOTAL PRODUCTIVE MAINTENANCE (TPM)

Total Productive Maintenance is a representation of lean topics and their importance in the improvement process by implementing preventive and proactive strategies (Figure 1.13):

The foundation of this diagram is:

- **Safety and Environment:** Responsibility for the environment and safety for employees is the foundation of the process.
- **Education and Training:** On the second layer above safety and environment is the education and training block. By teaching the correct knowledge, especially for specialized processes and equipment, lean operations goals can be achieved.

The five pillars of TPM are:

- **Quality Integration:** The equipment should be fitted to and capable of producing parts within a designed capability range. Overuse or improper use creates maintenance issues.
- **Old equipment improvement:** It is not always necessary to replace the old equipment. It can be repaired and updated.
- **New Equipment Management:** New equipment management involves the right vendor selection, maintainability in the long run, and training

Figure 1.13 Total Productive Maintenance of lean production is achieved through applying the foundation and pillars of this diagram.

personnel to operate them.

- **Autonomous Maintenance:** Autonomous maintenance assigns responsibility for routine check-ups including cleaning, lubricating, and inspection, and frees maintenance operators for other tasks.
- **Planned Maintenance:** Plan the maintenance of the equipment ahead of time.

Also, assigning a small group of employees to work together to produce an issue offers better results. This is called "focused improvement". TPM is not limited to the plant operation and could be used in the administrative functions as well.

1.5.7 ANDON LAMPS

Andon is often used in Toyota Production System and lean manufacturing to prevent producing defective parts. Andon translated from Japanese means sign or signal (Figure 1.14). Andons are visual alerts and highlight where the action is taking place, where the problem is, or where the line has stopped working. Andon is usually activated by a pull-chord or button and calls for a root cause analysis by the responsible operators. An immediate response is required to identify the issue and to fix the problem (Figure 1.15).

Figure 1.14 Traditional Japanese andons are lamps made of paper stretched over a frame. The paper protects the flame from wind and creates minimum light in the darkness of night.

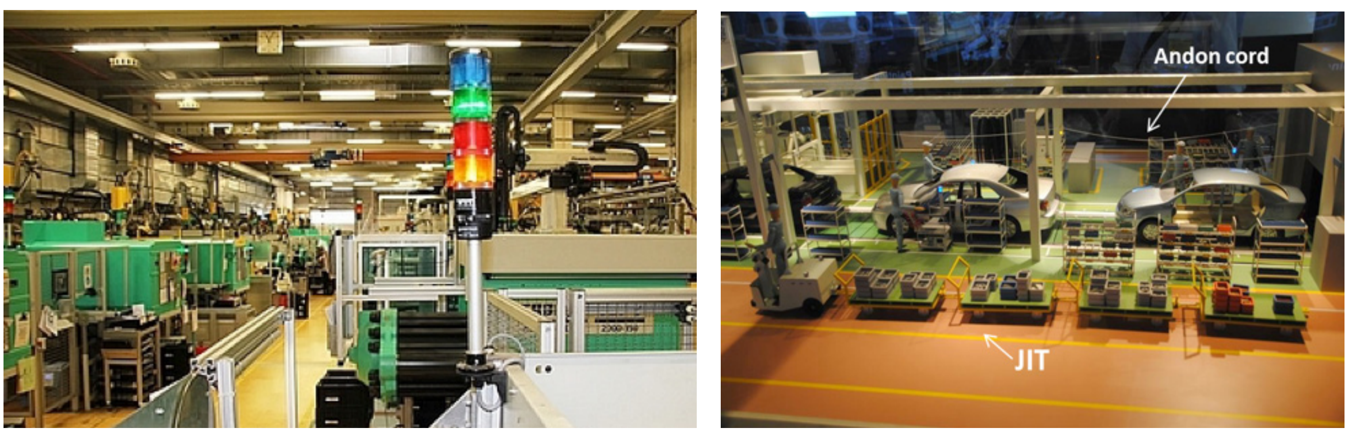


Figure 1.15 Right: Andon lights communicate and address a problem or defect. It signifies a state where attention is needed and triggers a set of reactions. Source: http://www.shmula.com/ Left: An alternative to the andon lights is a pull chord that performs the same function as of the andon lamps. Source: www.dpaonthenet.net

1.5.8 A3 THINKING AND PRACTICAL PROBLEM SOLVING

A3 is the size of 11x17 inches paper that can be used to identify the problem and develop brain-stormed ideas and suggestions to solve the problem. This method was first used by Toyota Lean manufacturing practitioners. Toyota trainers call this the "storyline" of the problem solving report. A3 is also called SPS (Systematic Problem Solving) based on the principles of PDCA management (Plan-Do-Check-Act) (Figure 1.16 and 1.17). Most often, there are 8 steps used in the **A3 thinking process**:

PLAN:

What?

1. Problem description
2. Break-down the problem (What, where, when, why, who, how, and how many?)
3. Set target

Why?

4. Analyze the root cause

How?

5. Cause and effect analysis

DO:

6. Follow up action and implementation of counter-measures

CHECK:

7. Monitor results and process

ACT:

8.Standardize and share the successfully implemented action

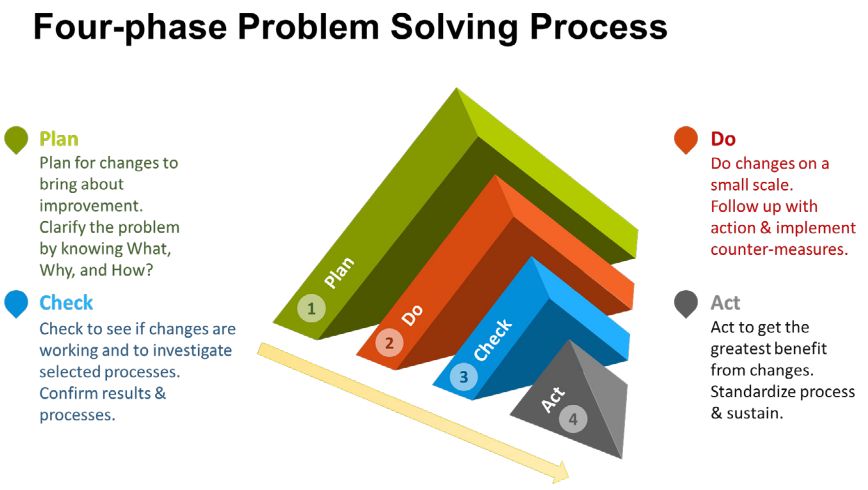


Figure 1.16 The principles of PDCA management (Plan-Do-Check-Act) usually is drawn on an A3 size paper which is a good size for a quick brain storming and seeing the connections of the subsystem.

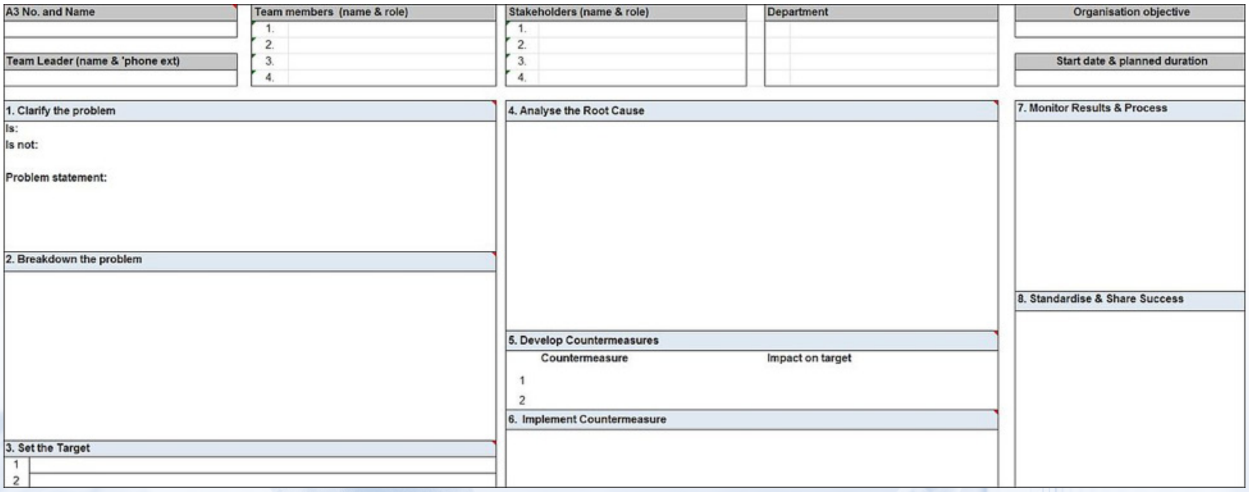


Figure 1.17 This table can help the person in charge of the practical problem solving. A standardized organized sheet, which is similar for all users, helps to develop an understanding of the issue at hand and speeds up the solution process.

1.5.9 ERROR PROOFING OR POKA YOKE

Any mechanism in the lean manufacturing process that can help an equipment operator to avoid mistakes is "error proofing." Shigeo Shingo introduced this concept in 1961 as Poh-kah Yoh-kay which basically means "fool-proofing" of a system (Figure 1.18). For example, when a car is in the park position/gear it cannot move. This is a design solution that makes operating a car safe. The same procedure can be applied in a factory setting to prevent human error. Mr. Shingo suggests three types of error-proofing method:

1) Contact
Testing the product's shape, size, color, or other physical attributes

2) Fixed-value (Number)
It warns the operator that one step is missing.

3) Sequencing/Control
Determines if the steps of the process have been followed.

Did you know?

Shigeo Shingo, then an industrial engineer at Toyota Motor Corp., introduced the concept of poka-yoke (pronounced POH-kah YOH-kay) in 1961. Shingo's initial term was bakayoke, which means "fool-proofing." In 1963, a worker at Arakawa Body Co. refused to use baka-yoke mechanisms in her work area, because of the term's dishonorable and offensive connotation, and subsequently the term was changed to poka-yoke, which means "error-proofing" or "mistake-proofing."

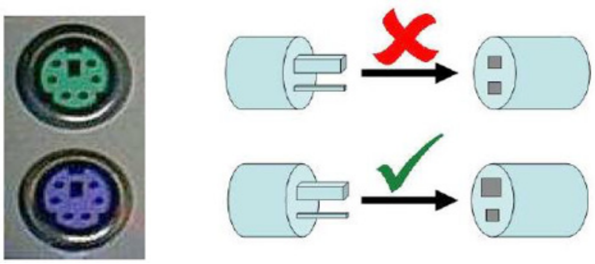


Figure 1.18 By designing the initial process in a way that the possibility of errors is already eliminated, there is less time needed to train employees, and fewer quality control problems.

This method has many advantages such as spending less time to train employees, reducing quality control problems, and avoiding repetitive operations.

1.5.10 THREE-PS (3P) PRODUCTION PREPARATIONS PROCESS

The Production Preparations Process is a powerful means for creating a new product design or a significant change of process development due to poor quality, or to respond to a high risk or high reward customer demand. Unlike Kaizen that is about incremental changes, a crossfunctional team of as many as 20 people unleash their creative solutions for about a week to make significant changes in the production process (Figure 1.19). This usually involves product and production layouts which lead to creating mock-ups and finally blue-prints.

Phases of 3P:

1) Define the problem
2) Set goals and objectives
3) Analyze and diagram
4) Screen and examine the ideas
5) Moonshine the best: build a mock-up
6) Select the process and the design blue-print

Figure 1.19 A cross-functional team of as many as 20 people unleash their creative solutions for about a week to make significant changes in the production process where new product design or an improved change is necessary. Source: leanhealthcarewest.com

1.5.11 VISUAL CONTROLS

Visual control is a system of signage, color-coding, lay-outs, material storage and information displays. This is a means for controling and smoothing the placement and direction of the flowing parts in a production process. Examples of visual controls are seen in the figures below. In Figure 1.20, all equipment's outline is marked on a board where they will be displayed and stored for easy access. Also, the lines on the floor suggest where the operators are allowed to walk before causing interruption with other activities in the plant.

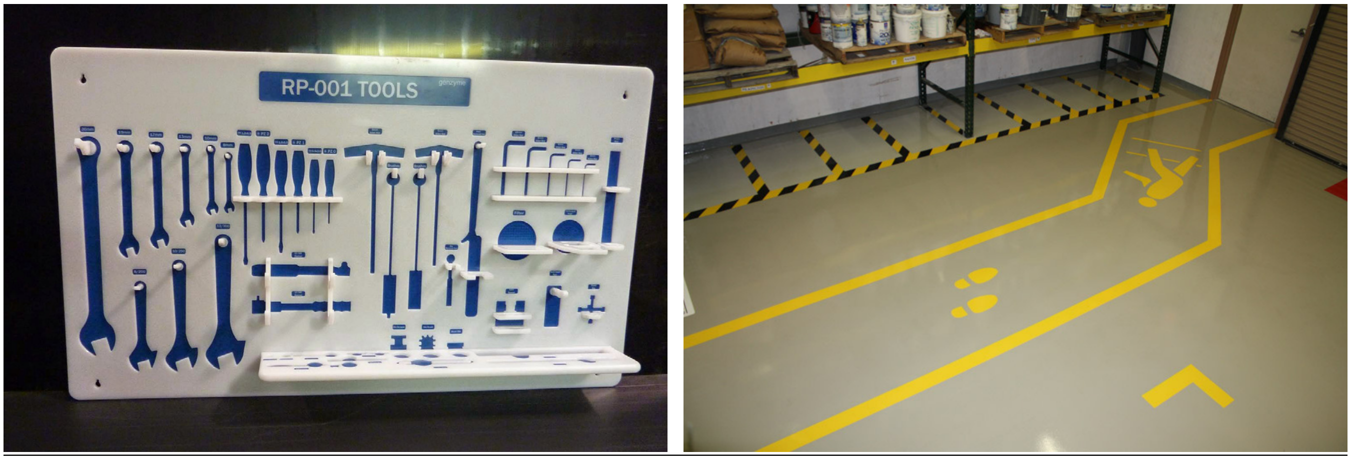


Figure 1.20 Visual Control Method is not only quite helpful for communicating with the workers who face a language barrier but also makes the flow of movement and organization easy for all members of the team. Sources: myleanjournal.blogspot.com and www.mccordcontractors.

1.5.12 SUPPLIER DEVELOPMENT

A lean supplier development program is required for a healthy and successful supply chain. The supply chain must have reasonably low costs, a profitability plan for all participants, higher product quality, and perfect ontime delivery. The most important two functions of this program are to provide the supplier the right supply chain information and to build a long-term sustainable relationship with the supplier. If this relationship is based on trust and an early flow of information, the production flow continues without delays and waiting interruptions (Figure 1.21).

Figure 1.21 A smooth flow of delivery is the result of a healthy relationship with the supplier.

1.5.13 SUPERMARKETS

A **supermarket** concept is a right-size inventory strategy of stocked and ordered goods that need to be available to prevent a potential bottleneck (Figure 1.22). For example, if a machine is meant for multiple products putting a supermarket and component visibility stack right before the machine, assures that the potential bottleneck always has the right and enough parts to run. Also, in changeover processes and the in-between phases of the operation, supermarkets can reduce lead times considerably. The availability and quality of the items should be based on a pull system of production where stocking is triggered at the appropriate time.

Inventory strategy:

Replenishment is based on the demand for stocked items on the shelf. Consumed items must be detected by the supplier to allow timely replenishement.

Figure 1.22 The supermarket idea is used for an effective inventory where the required parts and their availability are identified and assured. Source: bar-coding-andidentification.wikia.com

QUESTION SET 1.5

1) Describe value stream mapping. What is the goal using this method? What are the components of value mapping?
2) Name and explain Five-S Housekeeping.
3) Why is the Ishikawa diagram known as the "fish-bone" diagram? What does the head of the fish-bone symbolize?
4) What is optimum cellular performance? Why?
5) What does SMED stand for? How does separating the activities into two groups help the process?
6) What are the foundations of TPM?
7) Why do you think it is useful to use Andon lights in the factory?
8) Where does A3 Thinking gets its name? Would you use this technique in a manufacturing plant? Why?
9) Provide an example of an error proofing mechanism around you?

1.6 ADVANTAGES AND EFFECTS OF LEAN THINKING IN MANUFACTURED CONSTRUCTION

To summarize the content of this module and review the main objectives of lean thinking, we can point out the major goals of thinking lean in manufactured construction:

- Reducing the waste chain (time, material, energy, and cost)
- Reducing inventory
- Reducing floor space
- Reducing production timing
- Meeting expected time-deliveries
- Increasing a better communication
- Increasing a respectful team culture
- Involving the client
- Increasing production flow
- Sustaining relationships
- Sustaining equipment
- Increasing safety
- Educating and training
- Efficient problem-solving

1.7 OVERLAPPING SUSTAINABILITY AND LEAN CONCEPTS

The building life-cycle starts with a client's need and is translated into construction drawings, actualized through manufacturing and construction, and finally installed and used by its end user for a certain amount of time. The major goal of sustainable construction is to protect the environment, to protect the health of the people, and to use the least amount of materials and energy. On the other hand, in lean construction, the main goal is to increase efficiency, quality, and profitability in the production process. Lean originates in the manufacturing segment of the sustainability domain, but nevertheless can have similar effects, concepts and influences in tackling problems:

Waste Management

In sustainability, waste management reduces material and energy waste by planning ahead. In lean, waste management is tackled by reducing people, equipment, and transportation energy.

Long-Term Planning

In sustainable design, the emphasis is on designing and building in a lasting or sustainable manner. In lean, the goal is to create a sustainable or lasting team structure and equipment usage.

Health and Safety Factors

In sustainability, the goal is to eliminate harmful health related issues through good IEQ and IAQ, and the earth related problems through OEQ (Outdoor Environmental Quality) water, soil, and air cleaning strategies. In lean and specifically through TPM (Total Productive Maintenance), one of the fundamental foundations is employee safety and their environment.

Standardization

In sustainable initiatives, there is a requirement and encouragement for applying specific measures guided by established assessment systems such as LEED, Green Globes, LBC, and Energy Star. In lean, standardization is the main key for creating repetition, efficiency and a faster flow to achieve the economic goals of the company.

Respect and Team Culture

In sustainable construction, points are given for an integrative design process where team members are encouraged to be involved in several phases of the project such as Building, Design, and Construction (BD + C). In lean, the team culture is valued by respecting lower level employees, empowering workers, and promoting cross-functional team charrettes.

QUESTION SET 1.6

1) Name a few advantages of lean thinking in manufactured construction.
2) Explain why tackling waste management is a useful strategy from a lean and sustainable point of view.

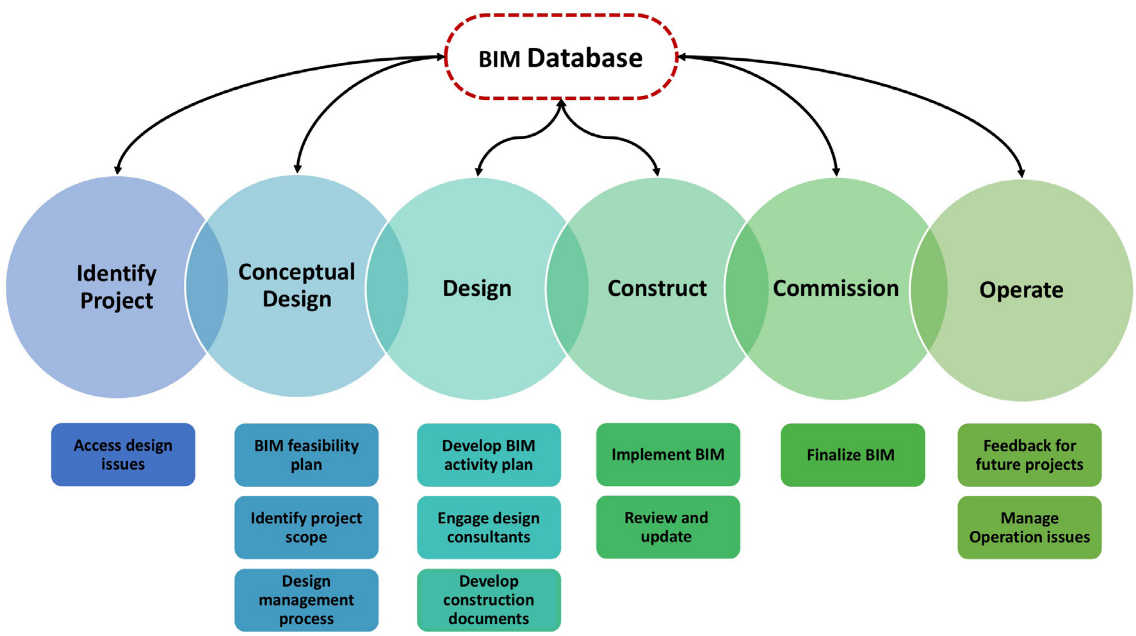
AUTOMATION AND ADVANCED INFORMATION SYSTEMS

Advanced automation and information management technologies are changing the paradigm of the building and construction industry. In the early 90s, the construction industry started to apply technology for improving productivity, safety, and quality, as well as reducing the duration and cost of construction operations. The primary objective was to apply computer-controlled processes and robotics to the construction industry. Applying automated technologies to manufactured construction can create a machine-centered process with no limits in performance, that is extremely productive, and capable of providing real-time manufacturing. This section introduces the state of the art technologies that can be used in different stages of construction and manufacturing industry, including design and information technology, supply networks materials management, planning and scheduling, fabrication, virtual reality, and simulation.

2.1 DESIGN AND INFORMATION TECHNOLOGY

The design process for a building requires an integrated information management system that engages users, technologists, contractors, consultants, civil engineers, mechanical and electrical engineers, and other specialists. The first phase of the design is schematic design and involves development of sketches and drawings based on the owner's (or customer's) requirements. Active cooperation of the design team members, as well as the participation of the stakeholders, can prevent expensive changes or mistakes in the design. Lack of collaboration and integrated design is known to be a reason for low productivity, rising costs, increasing risks, and adding waste in the construction industry. The key to improving integration and collaboration is better information management during all the phases of design, construction, and maintenance. The traditional approach to design and information management was 2D drawings and paper documents. This traditional approach failed to provide sufficient integration in large scale projects with an enormous volume of information and likely change orders. Therefore, a paradigm shift involving integrated databases is happening in the design industry. **Building Information Modeling (BIM)** is the most common technology used by professionals to boost productivity. The integrated and multi-disciplinary approach to the design and construction management using BIM technology is also called **Virtual Design and Construction (VDC)**. VDC is simply the application of BIM models in an integrated framework with several other required analysis and work processes for design and construction. As Figure 2.1 shows, a project has different stages, from project identification to project operation, and BIM is a practical tool for improving the performance and productivity in all these stages.

Figure 2.1 The project lifecycle includes design, construction and maintenance. Collaborative work is required between different levels and for each of the project stages. BIM is a tool to make the collaboration possible.



The manufactured construction industry is facing challenges of information management that hinder growth and decrease productivity in the factory. The information flow begins when a customer visits a dealer and customizes the house order. The engineering department provides the design documents for the production phase and the estimation of materials and product requirements. The manufacturing process for offsite stations and the main production stations must adhere to the design documents for each customized building. Figure 2.2 shows the information flow in a typical manufactured housing factory. As the industry grows, the flow of information will become more intense and more difficult to manage. Tracking existing materials in the warehouse, knowing material orders for upcoming projects, finding specifications for the ongoing project, and scheduling and planning for on-time delivery require an integrated database system such as BIM.

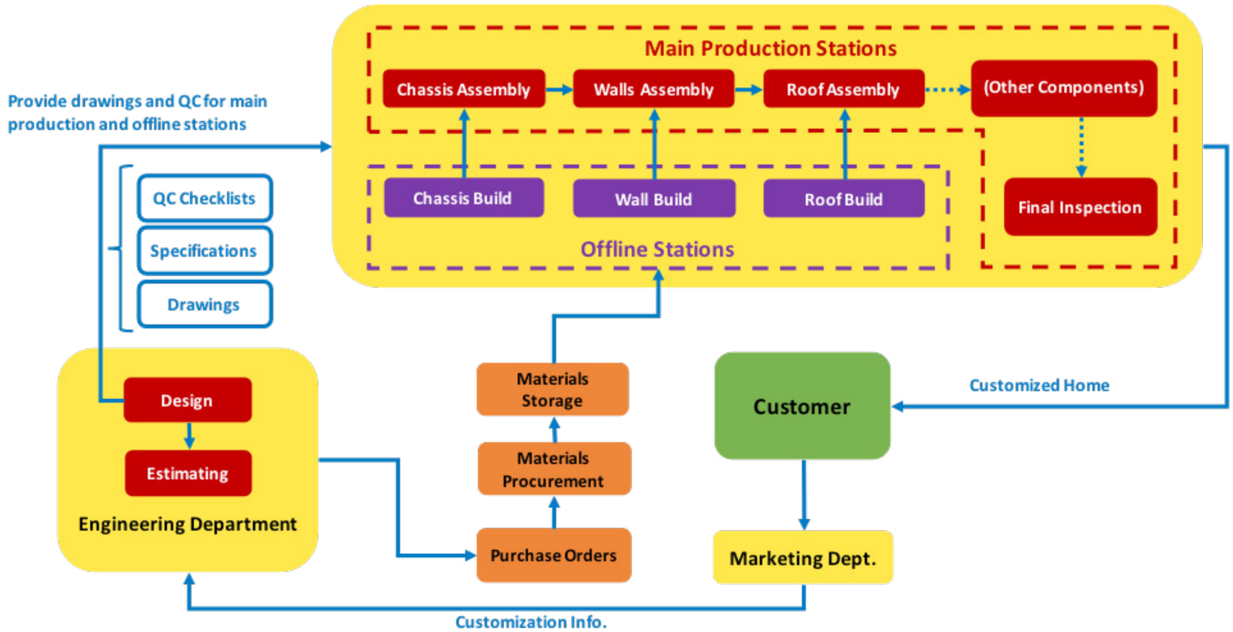


Figure 2.2 Information flow in a manufactured housing factory that starts from the customized order and ends with delivery of the customized home.

2.1.1 WHAT IS BUILDING INFORMATION MODELING (BIM)?

BIM is an object-oriented technology in which a virtual three-dimensional model of a building is digitally constructed. The model is composed of several objects like walls, doors, columns, and related information for each **"object"** assigned to the model. The BIM model integrates the geometry of each object with the related data to make a **"smart object"** (see Figure 2.3). The BIM model integrates architectural, structural, mechanical, and other design information and can gradually attach the new data into the model during the entire project. The model helps the design team visualize the project and identify any potential design, construction, or operational issues. The 3D model is also an excellent tool for visualization. Figure 2.4 shows an example of a smart object and the parameters assigned to the object in a BIM software, Autodesk Revit.

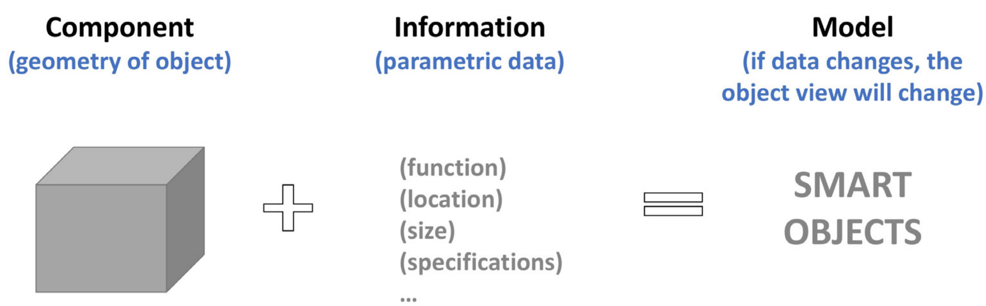


Figure 2.3 BIM model includes the geometry for each object and the data about the function, location, size, specification, etc.

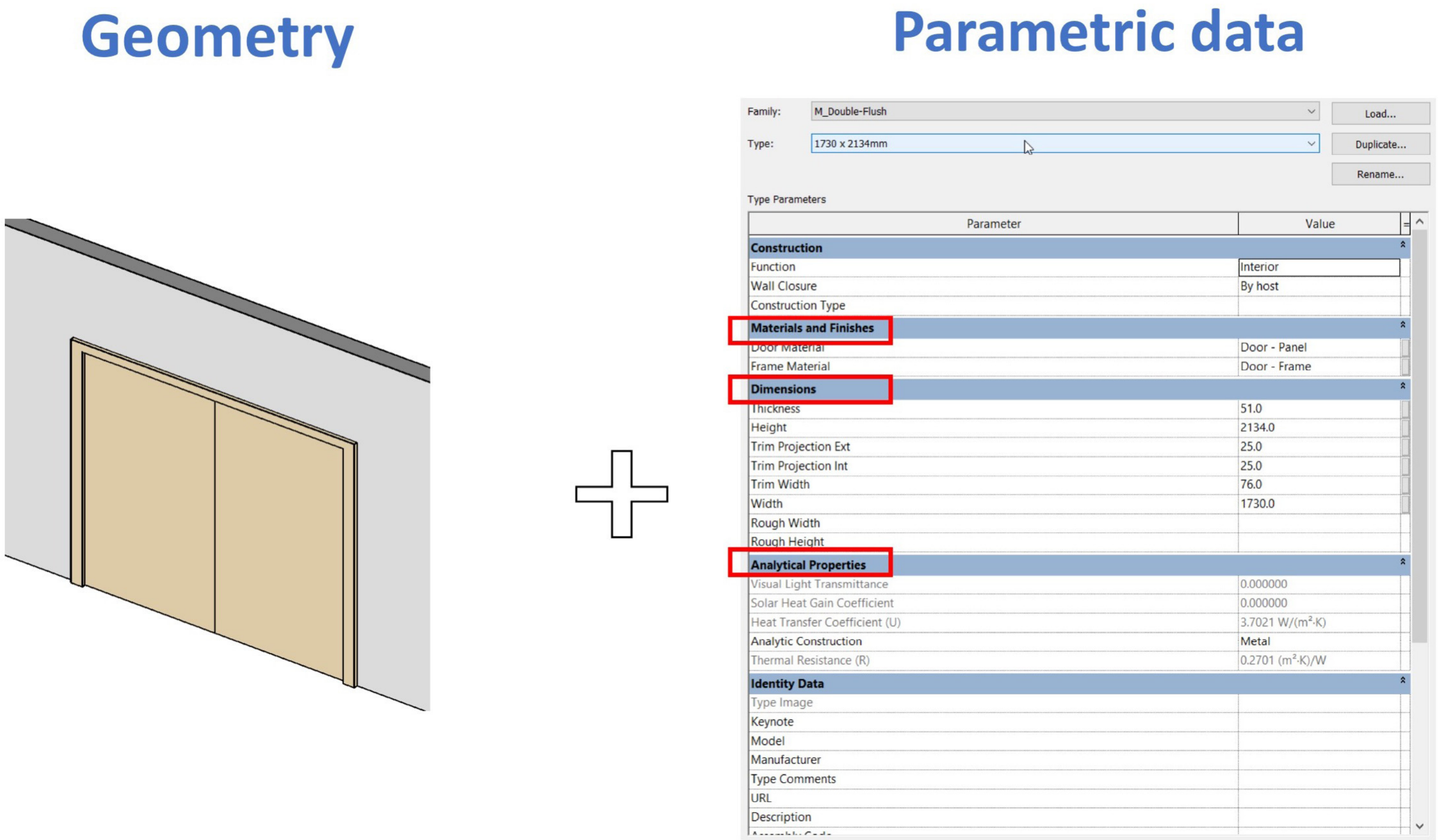


Figure 2.4 The Autodesk Revit interface shows information for the elements of a building.

Learning BIM software is the starting point for the BIM process. There are various BIM software tools available in the market for the different stages of the project, including the architectural, structural, mechanical, electrical, and plumbing (MEP) design; construction management; operations and facility management; and others (Figure 2.5). Autodesk is a leader in 3D design and engineering software. Revit is the a BIM software used for the design process, while Navisworks software is used for collaboration and management. Other major BIM software tools are ARCHICAD from Graphisoft company, Tekla from Trimble Company, and Bentley Systems from Bentley Company.

Architecture
- Autodesk Revit Architecture
- Graphisoft ArchiCAD
- Nemetschek Allplan Architecture
- Gehry Technologies - Digital Project Designer
- Nemetschek Vectorworks Architect
- Bentley Architecture
- 4MSA IDEA Architectural Design (IntelliCAD)
- CADSoft Envisioneer
- Softtech Spirit
- RhinoBIM (BETA)

Structures
- Autodesk Revit Structure
- Bentley Structural Modeler
- Bentley RAM, STAAD and ProSteel
- Tekla Structures
- CypeCAD
- Graytec Advance Design
- StructureSoft Metal Wood Framer
- Nemetschek Scia
- 4MSA Strad and Steel
- Autodesk Robot Structural Analysis

MEP
- Autodesk Revit MEP
- Bentley Hevacomp Mechanical Designer
- 4MSA FineHVAC + FineLIFT + FineELEC + FineSANI
- Gehry Technologies - Digital Project MEP Systems Routing
- CADMEP (CADduct / CADmech)

Construction (Simulation, Estimating and Const. Analysis)
- Autodesk Navisworks
- Solibri Model Checker
- Vico Office Suite
- Vela Field BIM
- Bentley ConstrucSim
- Tekla BIMSight
- Glue (by Horizontal Systems)
- Synchro Professional
- Innovaya

Facility Managment
- Bentley Facilities
- FM:Systems FM:Interact
- Vintocon ArchiFM (For ArchiCAD)
- Onuma System
- EcoDomus

Sustainability
- Autodesk Ecotect Analysis
- Autodesk Green Building Studio
- Graphisoft EcoDesigner
- IES Solutions Virtual Environment VE-Pro
- Bentley Tas Simulator
- Bentley Hevacomp
- DesignBuilder

Figure 2.5 BIM software tools are available for different stages of the project.

BIM can be used to connect design and construction to create a new, more productive and better-integrated process. The final BIM model includes the detailed geometry and quantity of each object, related data, geographic information, cost estimates, material inventories, and project schedule. The BIM model also has a multidimensional capacity known as BIM "nD" modeling. In other words, besides the 3D model, scheduling (time) information can be included as the 4th dimension, cost estimating as the 5th dimension, and other information such as safety and energy can be included as additional dimensions.

Many case studies and papers indicate how the implementation of BIM improves project productivity. A research paper evaluated 35 construction projects that were designed and constructed mostly in the late 2000s and mid-1990s. The study suggested that BIM is a useful tool for improving key aspects of construction projects such as preplanning, design, clash detection, visualization, quantification, costing and data management, communications, coordination improvement, and quality control. BIM also allows the users to keep track of the project, monitor its status, assign a future task, and send a request.

Clashes, incompatibilities, and errors in design are common in the construction phase of a project. For example, there may be a clash between structural steel beams or columns and the path of air conditioning ductwork. These types of problems, if not detected before construction begins, will cause expensive and costly delays. The BIM model makes clash detection easy and accurate in the design phase since it includes several models for each discipline, such as architectural, structural, and MEP. The architectural BIM model and its gridlines are the basis for all the other design models. After completing all the models, the clash detection process is run to determine where the models interfere. The BIM clash detection process finds the elements of separate models that are located in the same space, identifies incompatible parameters, and notifies the team that a time sequence is out of order (Figure 2.6).

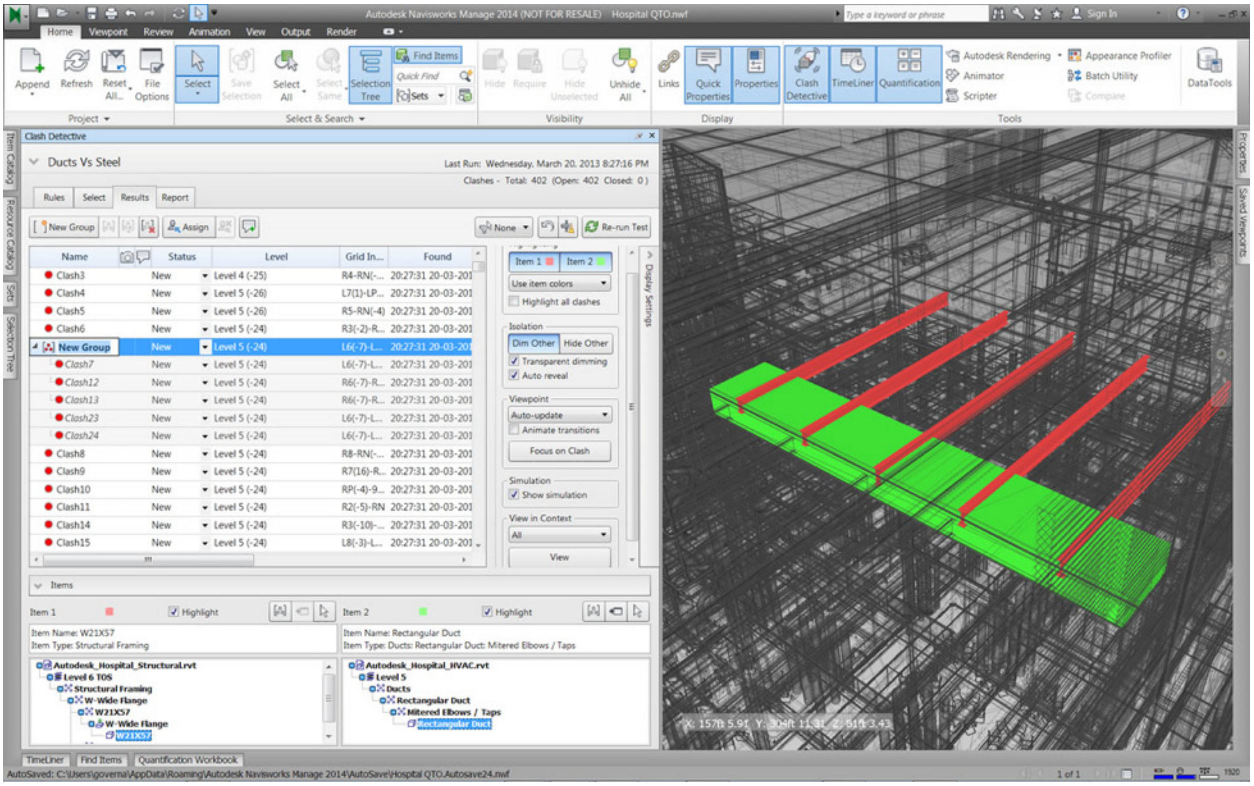


Figure 2.6 Navisworks software from Autodesk Inc. is a tool for clash detection and coordination. It also allows the experts to review integrated models and the clashes to make comments and ask for a revision. The figure shows an example of detected clash between wide flange beams in Structural model with a duct from Mechanical.

Several case studies show the benefits of BIM clash detection in the construction process including preventing delays, reducing design changes, decreasing materials costs, and saving overall expenses. In the construction industry, designers and contractors usually use BIM for 3D visualization, 4D planning, and clash detection to achieve better productivity and a considerable savings. For example, the Aquarium Hilton Garden Inn project in Atlanta, Georgia included a mixed-use hotel, retail shops, and a parking deck. The cost of project was $46 million and cost savings resulting from the use of BIM for clash detection was over $800,000. More than 590 clashes were detected before actual construction began. Figure 2.7 shows the benefits and barriers in BIM application in a project.

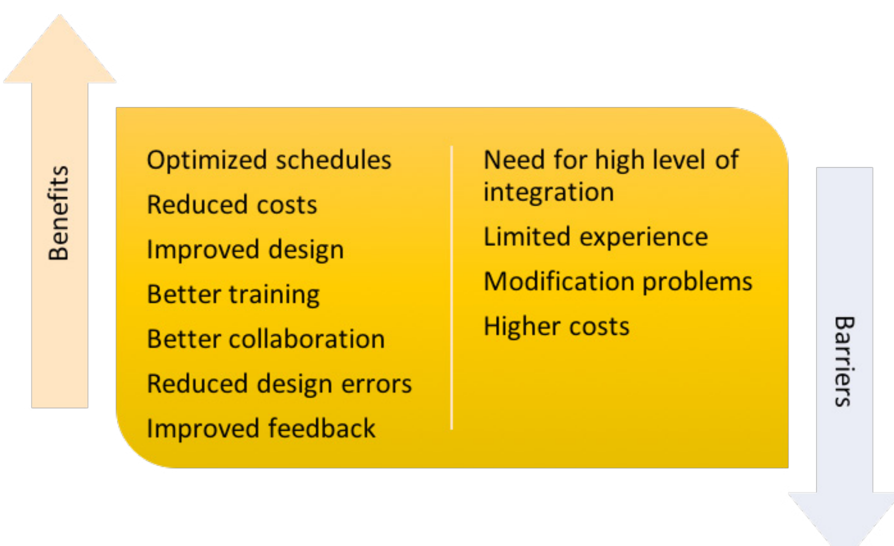


Figure 2.7 BIM has many benefits, but there are also some challenges. The major challenge is the lack of experience and knowledge.

2.1.2 WHAT ARE NEW TRENDS?

BIM provides the opportunity to develop and evaluate several design schemes and predicts the project performance to find the best design option. As a result, several new means of design optimization can be included in the BIM model as an additional layer of information. Growing implementation of BIM is changing the way of approaching design, construction, and operations improvement.

Sustainable construction is a critical topic in the construction industry because it addresses the impacts of its activities on the environment. BIM or BIM-related tools can be used for designing construction projects with minimum environmental impacts.

BIM has also been identified as an excellent tool for improving **construction safety.** BIM-based tools have been developed to evaluate the building design, identify safety hazards, and recommend protective measures to the users. As a result, the safety information for each object in the entire building can be available in the BIM model based on the location and type of the object.

Studies found multiple interactions between BIM and **lean construction.** BIM can improve lean construction in several ways by linking the lean strategies into the model and enhancing collaboration and integration.

One other benefit of BIM technology is making **facility management** and building maintenance easier and more efficient by facilitating the development of detailed as-built documentation. Several case studies demonstrated BIM benefits during the post-construction stages. There are also some efforts to develop BIM models for existing buildings using laser scanning or image processing technologies to take advantage of the benefits of BIM for building maintenance.

A recent important development for the Architecture Engineering and Construction (AEC) industry is web-based services. Web-based services are using the same information management approach as BIM but uses online applications as a collaborative interface for the team members. The number of web-based services is increasing and it is expected to be an essential part of project management tools in the near future.

2.1.3 BIM IN MANUFACTURED CONSTRUCTION

Due to the benefits of BIM in construction and manufacturing industries, there have been some efforts to apply these benefits in prefabrication and the off-site construction industry. The prefabrication factories need a high level of integration for controlling the processes and BIM can store a large amount of information about the objects and their construction and delivery process. Although all the applications show that BIM has been very productive for precast projects, there are a few applications of BIM in other types of manufactured construction, specifically for manufactured homes.

Due to the controlled condition in the factory, the off-site technologies can improve the speed and quality of construction and limit the design choices. Using BIM, factories can increase their work volume and quality, have better schedule and time management, develop more design alternatives, and improve the safety of the work environment. BIM can improve the efficiency of mass production and allow the development of more complex modular buildings. BIM can also provide all the benefits of management information systems in the factory including quality control of each building element to ensure that it is approved, fabricated, shipped, and delivered. Multiple team members can view the 3D model of the elements and share real-time information simultaneously.

The challenges in the implementation of BIM in the construction industry also apply to manufactured construction. The biggest challenge is overcoming the resistance to change. This will be possible if people understand the potential and benefit of 3D BIM over 2D design. Another challenge is training and increasing the BIM exposure for the employees. An investment is required in BIM software and licenses as well as hardware and systems to run the programs. Another challenge for applying BIM effectively is achieving collaboration and integration among the project stakeholders and providing a clear understanding of the responsibilities of each of them in implementing BIM.

Having a well-designed framework can help to overcome the challenges in the application of BIM technology. The learning process is easier with a bottom-up approach that helps the project members to learn by doing their work. In this way, people are engaged in the change and will accept it better, the company will improve the skills of the employees, and change management will be easier. The initial cost of software licenses and hardware development will be paid off by savings due resulting from the improvement in productivity and quality.

The BIM in offsite construction relies on capturing information from various stakeholders and using standard digital systems for information exchange and communication across trades. A study at University of Florida established a national BIM standard to provide the digital schema and requirements for efficient BIM application in the off-site construction. The standard covers the principal components of the BIM standard, including the Information Delivery Manual (IDM), the Model View Definition (MVD), and the Industry Foundation Classes (IFC) implementation. The development of IDM for off-site construction begins with definitions of the data exchange functional requirements and workflow scenarios for exchanges between architects, engineers, manufacturers, erectors, and general contractors. Figure 2.8 shows the framework proposed in this study for the application of BIM in offsite construction to improve value generation and elimination of wastes. The BIM framework consists of four major stages: design, manufacturing, subassembly, and assembly. Between the stages, a BIM exchange model is developed to store the information from various sources and provide a communication platform for all the stakeholders. The final output of the framework is an IFC model that is more powerful and closely reflect real project requirements and accelerate the use of BIM in off-site construction.

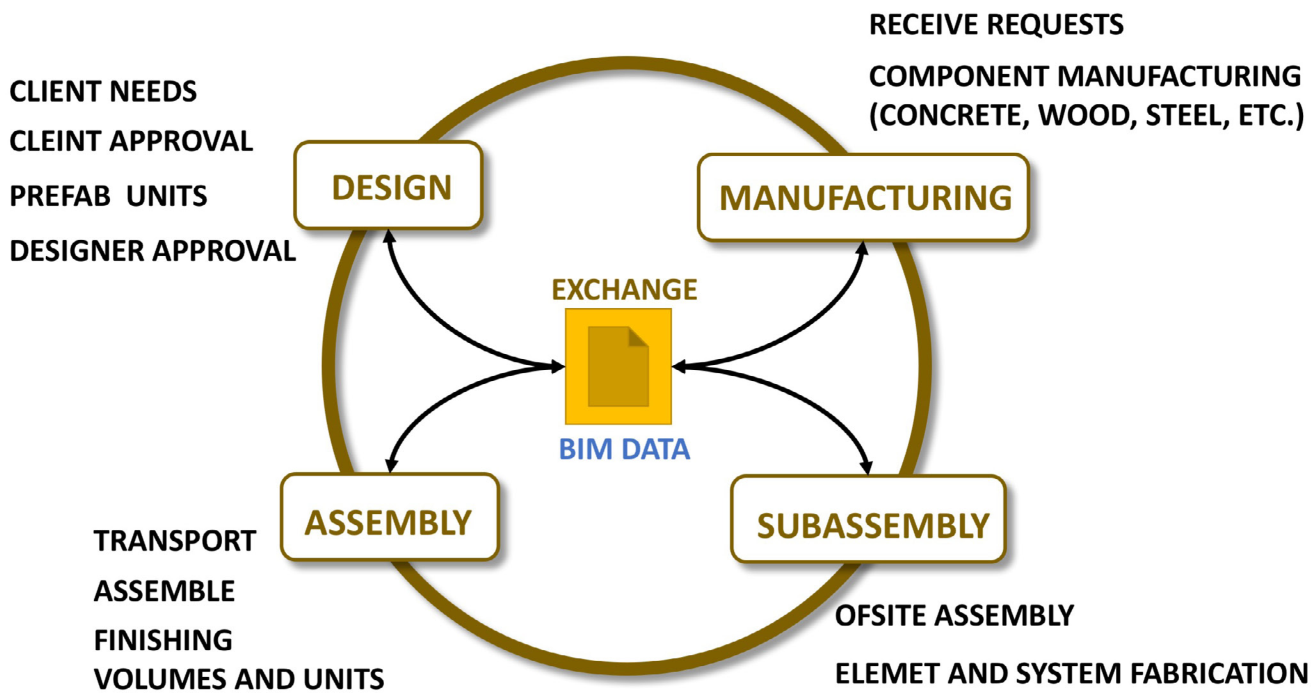


Figure 2.8 The proposed frameworks for application of BIM in offsite construction to improve value generation and elimination of wastes. In each stage of the framework, an exchange model is proposed for sharing information considering the exchange requirements (ER). D_EM is architectural, engineering design and prefab use case exchange models, P_EM.1 is prefab manufacturer and off-site assembly use case exchange models, and P_EM.2 is prefab manufacturer and on-site assembly use case exchange models.

QUESTION SET 2.1

1) How will BIM improve Integration in project delivery?
2) What is VDC and what is its difference with BIM?
3) What is BIM and How it is an object oriented software?
4) What is the meaning of BIM nD modeling?
5) What is the meaning of clash in project?
6) How can BIM improve clash detection?
7) What are some benefits and barriers in BIM application?
8) How can BIM application improve manufactured construction?
9) What are the challenges in applying BIM into manufactured construction? Propose the best approaches to confront these challenges.

A supply chain is a network of facilities and distribution options that procures materials, transforms these materials into intermediate and finished products, and the distributes these finished products to customers. Supply chain management is defined as “The planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers.”

Supply chain management is characterized by cutting costs, maintaining efficiency and quality, and providing value-added services from the original product manufacturer all the way down to the end consumer. Technology is an “enabler” for supply chain management systems and better efficiency, because of the automation that it creates. Technology is providing companies ways to become faster and more efficient in all areas of the supply chain, from the original product manufacturer down to the end consumer. One technology that has made a great impact on the supply chain is tracking technology.

2.2.1 TRACKING TECHNOLOGIES

Generally, a tracking system is used for the observing persons or objects on the move and supplying a timely ordered sequence of respective location data to a model. There are several tracking systems. Some tracking systems are 'lag time' indicators, that is, the data is collected after an item has passed a point for example a bar code. Others are 'real-time' or 'near real-time' like Global Positioning Systems depending on how often the data is refreshed. For the most part, the tracking worlds are composed of discrete hardware and software systems for different applications. The major tracking technologies in the supply chain are:

Barcodes.

A barcode is an optical representation of data relating to the object with which the code is synchronized (Figure 2.9). A barcode reader is used to read the information on the barcode using the light waves. The reader projects laser beam on the code which is sensitive to the reflections and upon the reflection and analysis of the space between the lines, thickness of the lines and identification of shapes, the data is interpreted by the reader and transferred to a computer for immediate action or storage. Immediate actions include the identification of objects, signaling and others.

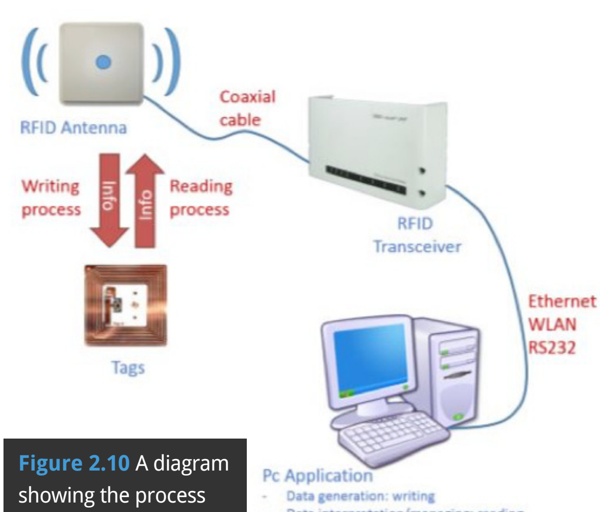


Figure 2.10 A diagram showing the process of information transfer using an RFID system.

Radio Frequency Identification.

Tracking technologies can be used to achieve more benefits in manufactured construction than available at present. The term ‘tracking technologies’ is usually mistaken as technology used for obtaining location, but tracking technology also relates with tracking of information, material and equipment. Radio Frequency Identification (RFID) and Near-Field Communication (NFC) are forms of tracking technologies that are used to locate and obtain information and data, whereas Global Positioning System (GPS) is a position tracking technology.

RFID refers to a branch of automatic identification technologies in which radio frequencies are used to capture and transmit data. A radio frequency identification system comprises of transponders or tags and a reader to communicate with the tag (Figure 2.10). Tags or transponders in the system can have readable or writable information or both depending upon the type of transponder.

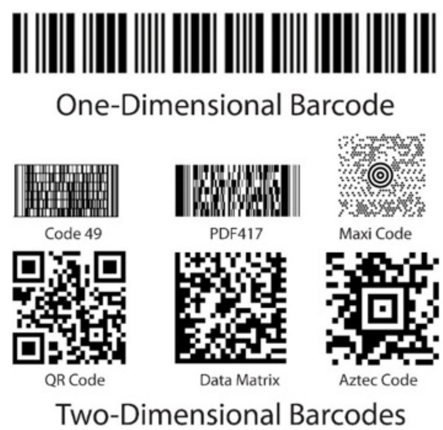


Figure 2.9 Examples of barcodes that are used for different purposes. There are at least 20 types of 2D barcodes. This picture provides the examples of just a few forms, mostly used in manufacturing and for high security purposes.

RFID technology is similar to bar code labels which uses light waves to read a tag whereas RFID system uses radio waves to communicate.

The use of RFID technology for the purpose of tracking material and quality management is not limited to the construction industry. The diverse application of RFID can be seen in several other industries; aviation, retailing, health, and logistics are some amongst others.

RFID tags have been developed extensively over the course of the past decade. There are three types of RFID tags; active tags, semi-passive tags, and passive tags. Passive tags require energy from the reader to operate, they have a less range of operation but better storage capacity compared to the active tags. An active tag includes batteries and are capable of transmitting the signal to the receiver. Active tags have a better range of operation so they can be read from a greater distance than most passive tags depending upon the quality and specifications of the active tag. Semi-passive tags can transmit the signal to the reader for a distance range of 60-80 meters but the tag is required to be turned on by a signal and backscattering is used to transmit the signal. Backscattering can be defined as reflection of waves, particles or signals straight to the source that is, through an angle of 180 degrees. This means the reader should be at an angle of 180 degrees to the tag to receive or transmit the information. Figure 2.11 shows specifications for active, passive, and semi-passive tags.

	Active Tags	Passive Tags	Semi-Passive Tags
Distance range	Up to 100 m	Up to 15 m	Up to 60–80 m
Power	Power supply (Battery)	Inducted from readers	Turned on by a signal
Relative cost	>30	1	>20
Data storage	Extendible and can vary	512 bytes to 4 KB	Extendible and can vary
Data transfer rate	Up to 128 KB/s	Up to 1 KB/s	Up to 16 KB/s
Lifetime	Up to 10 years	Unlimited	Over 6 years

Figure 2.11 Comparison between different types of transponders.

Near-Field Communication (NFC). NFC is a contactless technology used for communications between two devices. The technology uses the same concept as RFID and uses radio signals to communicate with other devices. NFC technology is a simple extension of RFID, supported by mobile device manufacturers, infrastructure and technology manufacturers, as well as by all major payment providers. The communications distance between two devices is limited to 10 cm in NFC. The use of NFC is intended for making transactions, exchanging content, and connecting electronic devices with a touch. The procedure of making connections using this technology is very much similar to a human communicating by means of touch. Although NFC is in the very early phases of research, it is compatible with RFID which will make it much less daunting and more accessible. NFC technology is generally used to transfer requested data between two NFC supporting cell phones. NFC can be used for payment purposes, tracking and locating objects within close proximity. It can be used where the behavior of the action is responsive. For example, an NFC tag or transponder is attached to a key and synchronized with a cell phone. If the keys are lost within the range at which the NFC transponder operates, the cell phone can be used to find the key by requesting a signal from the tag (a beeping sound for example).

NFC technology can thus help locate objects and materials in the material storage area or offline stations in a manufacturing facility. It can also help workers place components, such as doors and windows, in their exact position. This technology can also help in obtaining the stage and station of a current project in the factory from a central location within the factory.

Figure 2.13 demonstrates integration of two types of tracking technologies in the process of home manufacturing. These technologies are RFID and NFC. RFID, which is a technology that is used to determine data on a reader with the help of a transponder, can be used to incorporate information and retrieve information such as drawings and checklists whereas NFC is a responsive kind of technology and can be used in the process for locating materials on offline stations or in the storage.

As Figure 2.12 shows the process of integration of technology into the manufacturing process starts with the marketing department. The information that can be incorporated on the transponder at every stage is explained below with numbers indicated on the figure for every department or section where the information can be incorporated or retrieved.

1) Customer brings a set of requirements to the marketing

department. The marketing agent transfers all the information to the RFID transponders. This information includes customer name and contact information, customer ID, project details, site information, and any specific requirements. The marketing agent then transfers the information saved on the transponder to the engineering department for design development.

2) The engineering department incorporates the information on the transponder into the design and develops drawings, specifications, quality checklists, and permit documents. The use of softcopy drawings can reduce the chances of error in drawings and any miscommunication or loss of documents can be avoided. Engineering department can store all the important documents that are required for the completion of project on the tag. This information can be read with several readers available at all stations but limited information can be modified from a central location.

3) The process of manufacturing starts with building the chassis. Chassis usually have standard dimensions according to the size of the house. There can be one or more number of chassis depending upon the size and type of project. Chassis is a component that travels all along the main production line. RFID tags can thus be installed on the chassis. At this stage RFID tag incorporates all the information about the project.

4) From this stage the RFID tag gets updated with marked checklist and inspection and moves further to other stages until stage 8, which is the stage for final inspections by the governmental authorities and the factory inspector before releasing the structure for transportation to site. Final inspection reports can be accessed online by the inspection authorities with all data available on the tag. Any response provided by the inspection authorities can be recorded on the tag and because the tag can be linked with the internet, all the records can be made available to authorities on cloud. Stage 9 includes providing all the documentation relating to warranties, product guidelines, ~~structural information, drawings &~~ specifications and any other relevant information to the owner.

In parallel to using RFID, other technologies such as NFC and bar codes can also be used for procurement of materials, material storage, and the offline stations 9NFC 1a, 2a, etc.).

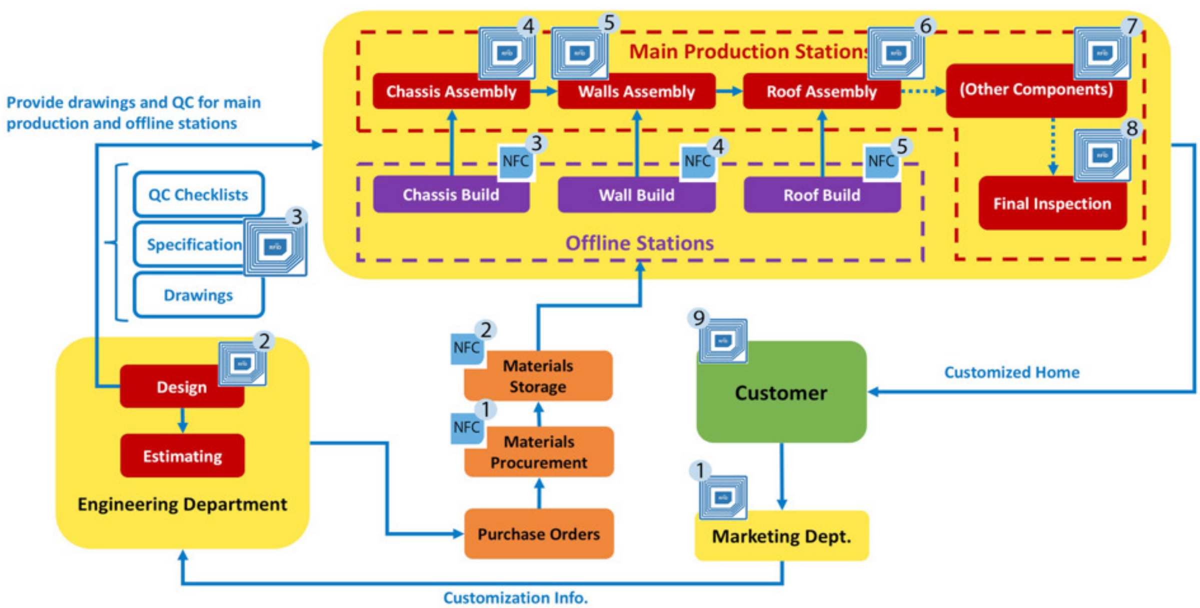


Figure 2.12 12 Integration of tracking technologies in the process of manufacturing. RFID tags can be installed in the chassis which will travel through different station on the main production line. NFC tags can be used on offline station. The numbers indicated on the tags are to describe the process.

Global Positioning System (GPS). GPS is used to track objects or subjects from space within a few meters of their exact location. Since the early 1990s GPS has become a globally pervasive source of free and highly precise positioning and timing information. GPS is used for many purposes, among them telecommunications, electrical power distribution, and transportation. GPS has three segments; space, control, and position locating system. The space segment consists of a number of different satellites, whereas the control segment consists of a worldwide network of tracking stations and ground antennas. GPS originated in United States in the late 1970's, and is widely recognized as world's the most accurate method of navigation. Being an embedded technology, the GPS is not generally visible in personal computers, automobiles, surveying equipment, weather tracking systems, military munitions, electronic receivers, and other products incorporating the technology. This technology is rapidly becoming as much a part of our daily lives as the internet. It is now being used to navigate and locate vehicles, ships, and wildlife. GPS provides continuous positioning and timing information for a subject and/or object being tracked, anywhere in the world and under any weather conditions.

2.2.2 PROCUREMENT OF MATERIALS

Procurement of materials in a timely fashion is essential in manufactured construction. Manufacturing a single family house in a factory takes less than 3-6 days. With this pace of manufacturing it is necessary for the factory to procure the construction materials ahead of time. This requires use of the latest technologies, such as building information modeling and tracking technologies in the manufacturing process. Building information modeling can be used to estimate the quantity of materials in a project. Any modification in the project will immediately update the bill of quantities and eliminate the time consuming practice of manual quantity estimation. Intelligent and automated data collection technology such as the use of barcodes and RFID can be incorporated for tracking materials. Research shows that in the future, advance technologies in combination with building information modeling can be used to automatically send purchase orders to materials suppliers for just in time delivery to the factory.

Tracking prefabricated products during their transportation from prefabrication plant to the project site for assembly is an important task. Distribution of the finished products is also a very important task in order to maintain the production schedule and productivity in the whole facility. As the construction industry advances, the use of prefabricated elements for construction is becoming very popular because of increased speed and better productivity.

Case study

Some companies have been using RFID technology to track the materials while are being transported from the manufacturer to the jobsite. Moreau Construction, a Quebec based construction firm, adapted RFID tags to streamline the tracking of its power tools in the factory.

Gammon steel, a Hong Kong based steel fabrication company uses RFID tags for tracking and locating the components in their projects. Gammon steel employed Tecton Ltd., a Honk Kong based building information management company, to assist in tracking their products from fabrication at the factory to installation at the jobsite. For the past few years Tecton has been providing RFID solutions to track modular components to reduce the incidence of errors and ensure that the components are onsite when required. Construction companies typically lack a centralized site for tracking where all their assets are stored. Paper records kept onsite can become lost or be incorrect, and are often not timely since they can only be input into a computer system after being brought to the office. In the event that an error is made during construction—such as an incorrect piece of framing being erected on part of the building—that mistake may not be caught until the concrete is poured. RFID, on the other hand, electronically stores location and status data about the assets being used during construction, so that onsite construction managers, or staff members at remote locations, can view which items are being stored or installed as construction takes place.

2.2.3 TRANSFORMATION OF MATERIALS INTO IMMEDIATE AND FINISHED PRODUCTS

The degree of automation in the production of construction materials such as cement, steel, aluminum, glass and wood is very high – almost 100%. Automation and robotics are also common in production of pre cast concrete elements by using robotic cells which can execute various tasks such as setting molds, placing reinforcement bars or mats, and distributing concrete for various products such as floors, roofs, walls, beams and columns. Automation is the key to efficient materials transformation to benefit the manufacturing process. Many fabrication companies are using automation for prefabrication of components to automate the process.

3D printing can be a useful technology for transforming materials into finished products. 3D printing is the process of making physical objects using a three-dimensional digital model of the object. A machine lays successive thin layers of materials to produce a physical object. Initially, 3D printers were very small in size and could only print small parts, approximately 3" X 3 ". Due to rapidly improving technologies, 3D printers are now large enough to "print" an entire building.

Complex shapes are considered time consuming and not economical in the manufactured construction industry. Custom shapes have been a limitation to the manufactured construction industry due to the time consuming process of creating them. 3D printing can potentially prove helpful for creating complex shapes, such as one shown in Figure 2.13, and can save time and money. 3D concrete printing, when combined with a type of mobile prefabrication center, has the potential to reduce the time needed to create complex elements of buildings from weeks to hours.

Figure 2.13 A complex shaped building element being created 3D printing.

QUESTION SET 2.2

1) What is the definition of supply chain management?
2) How can technology impact supply chain management?
3) What is the difference between lag-time and real-time tracking systems?
4) What are most common tracking systems in manufacturing? Explain each briefly.
5) Compare passive tags and Active tags in a RFID system.

2.3 DESIGN AND INFORMATION TECHNOLOGY

2.3.1 PLANNING FOR EFFICIENT PRODUCTION LAYOUT

The design of plant layout must consider location of equipment, materials, amenities, and employees such that the space is utilized efficiently and materials handling is minimized. This includes:

- Ensuring that labor is used efficiently
- Eliminating bottlenecks
- Providing proficient communication between workers and supervisors
- Eliminating downtime
- Ensuring material/product movement is not static
- Considering flexibility for future workflow changes

An organized layout will increase the productivity and efficiency of the production and reduce delays. Different optimization modeling and simulation tools are used to find the optimal layout design based on specific plant conditions. In this sort of problem, the first step is determining the model parameters and constraints based on the plant situation. The next step is finding the best simulation approach and equations for the problem. Since the problem is usually complicated, solving the model can be challenging and time-consuming. As a result, the final step is finding the best method to solve the problem and implement the solution using a computers and software.

A manufacturing system includes several planning stages. Plant location and plant design are two main areas of planning manufacturing systems. Plant design may have different stages including facility system, layout design, and material handling (Figure 2.14). Each of these stages presents complex decision making problems.

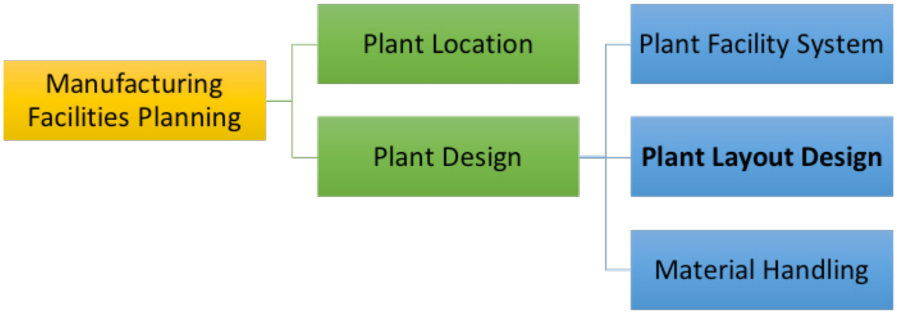


Figure 2.14 An effective decision making process is required for planning a manufacturing system. Two main areas of the planning are plant location and plant design. Plant design may have different stages including facility system, layout design, and material handling.

The same problem is raised in onsite construction projects when **site layout is designed** to locate temporary facilities, materials storage, and other important resources. The same decision-making tools are used for solving these problems considering various site constraints. Figure 2.15 shows the common steps for designing the site layout for construction projects. Studies show the application of information technology (such as 4D simulation using BIM) and digital technology (such as artificial intelligence and virtual reality) are effective in the optimization of the construction site layout. In the case of manufactured construction, the problem is plant layout, not site layout. In the case of manufactured construction, industrial and manufacturing engineering and supply-chain management are used to assist in designing the layout. The U-shaped factory floor is the most common layout in manufactured housing plants, although other layout options may be more efficient.

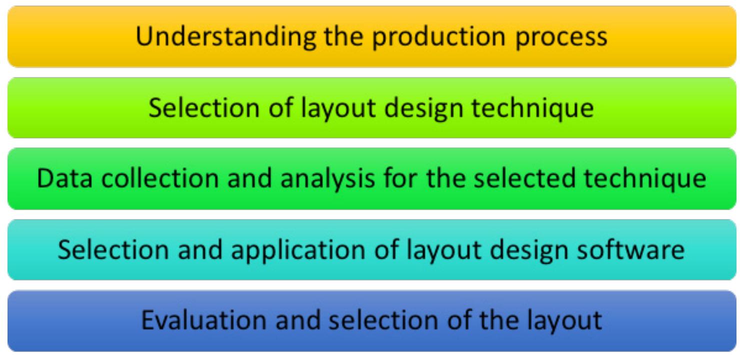


Figure 2.15 Five Steps in designing the site layout for construction projects

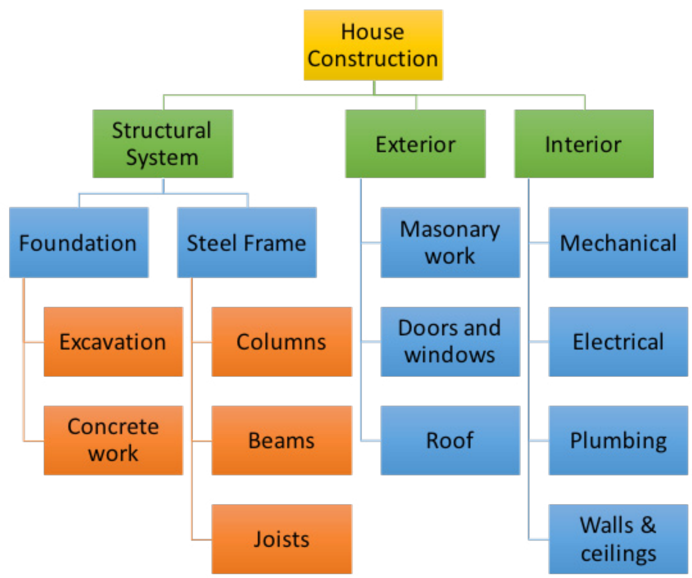


Figure 2.16 is a hierarchical breakdown of the project into phases, deliverables and work packages. It is a basic tool to find the scope of project and a useful tool for scheduling and planning.

2.3.2 OPTIMIZING PRODUCTION SEQUENCES

Production scheduling is optimizing the sequence of operational tasks and allocation of limited resources over time, considering the constraints of the system and the expected quality performance. Scheduling is an important process in any manufacturing and industrial service to plan the sequence of the given tasks and manage specified resources. Although production scheduling is very complex, an efficient and optimized schedule can have considerable impact on manufacturing productivity. For optimizing the production schedule and cost, other important criteria are: environmental load, waste generation, and energy demand. Figure 2.16 shows one of the most common techniques to find the scope of a project and to find the project activities is **work breakdown structure (WBS).** Two basic scheduling techniques that use activity information from WBS are the **bar chart** or **Gantt chart** (Figure 2.17) and the **network diagram** (Figure 2.18).

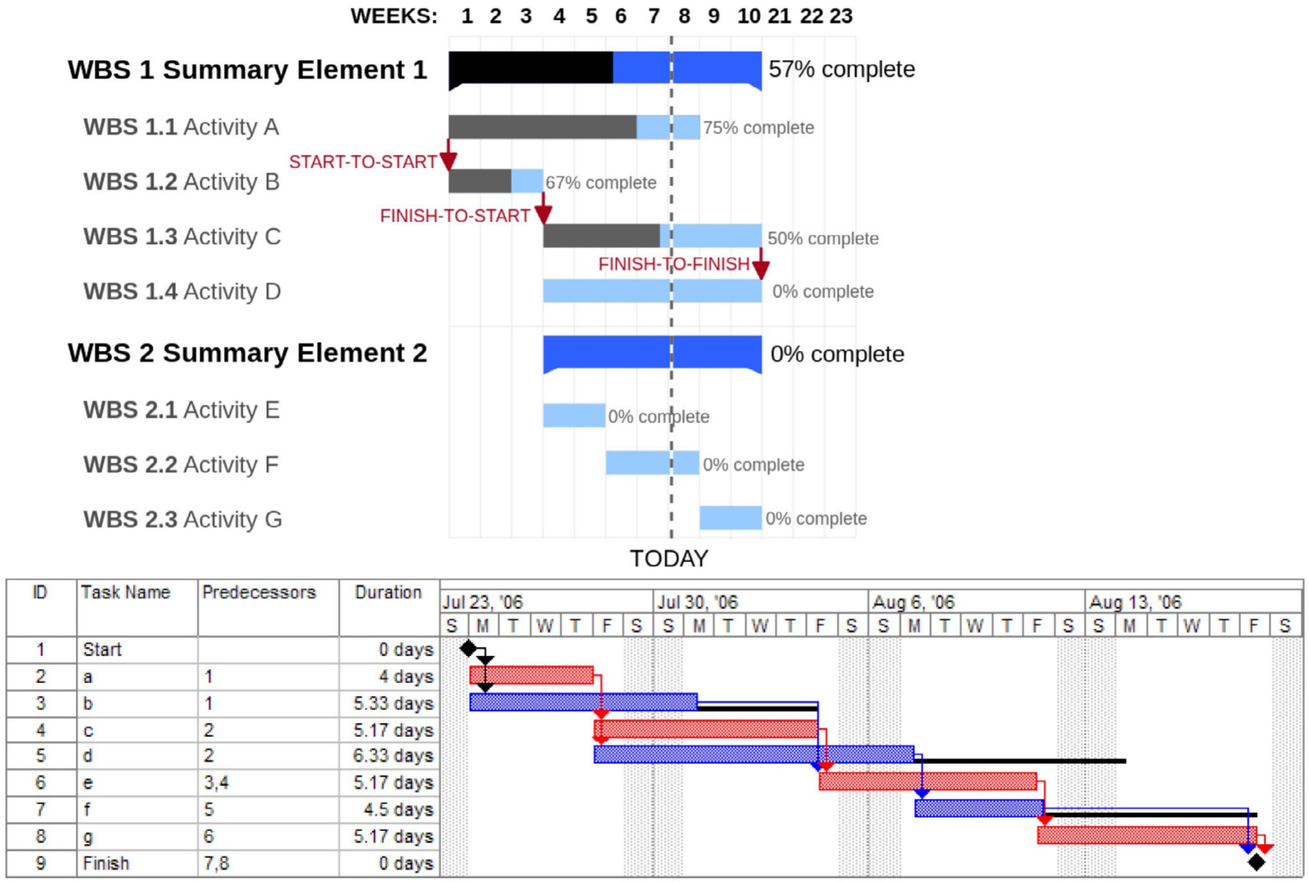


Figure 2.17 The Gantt chart is a type of bar chart to visualize the activities from the WBS with the start and finish dates and the critical path of the project. It also shows the dependency and relationships between activities and the work progress.

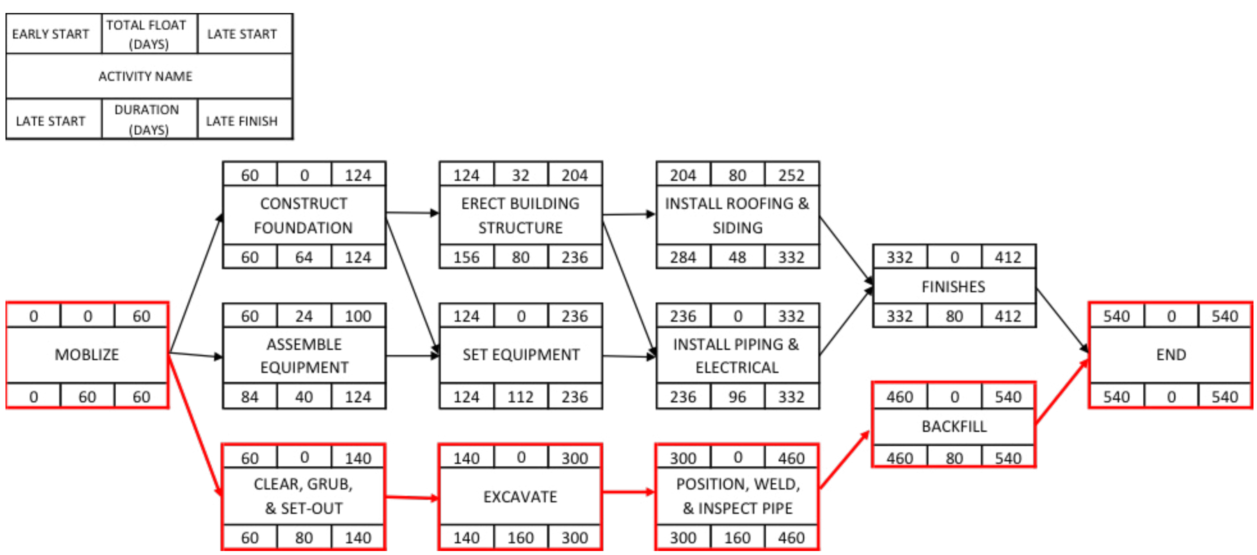


Figure 2.18 is a tool for planning the sequence and timing of a task. All activities from the WBS are included and their sequence and duration are estimated. The CPM is used to determine the duration of for a project. This figure is a simple example of a Water Pumping Station and Pipeline Project. As the picture shows, the construction process for the pipeline takes longer than the pumping station. As a result, the activities for pipeline construction (Shown in red) are on the critical or longest path.

Scheduling is a type of decision-making problem with the primary focus on time and resource management in the manufacturing process. For each task, the production schedule determines task duration, resource allocation, prerequisite tasks, and the expected output. There are several scheduling models and approaches applied in different industries to satisfy specific features and conditions of the production. Figure 2.19 shows the timeline for evolution of scheduling methods. The scheduling approaches are classified into deterministic and stochastic models. Some of the standard deterministic approaches are computer-supported scheduling (Such as interactive Gantt charts), expert systems, mathematical programming (such as linear programming), heuristics, metaheuristics, evolutionary algorithms and artificial intelligence methods. Stochastic models consider uncertainties and unpredictable real-time events (such as safety issues, machine failures, supply and demand changes, due date changes, etc.) that are very likely in the dynamic production environment.

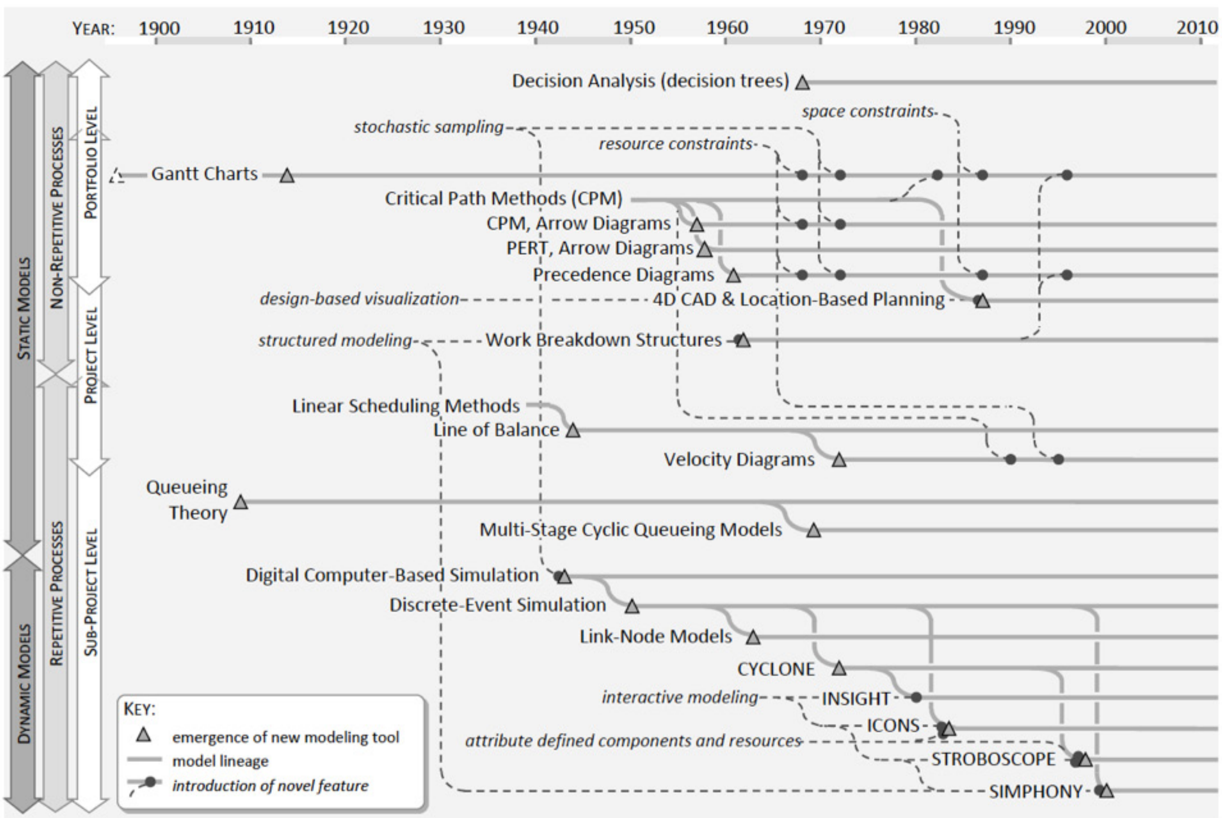


Figure 2.19 The formalized methods of construction project planning are categorized to dynamic or static models, for repetitive or non-repetitive activities, and in Sub-project, Project, or Portfolio level.

Developing a schedule for manufactured housing is more straightforward than construction projects. The manufactured construction process does not have major changes, but the construction project schedule requires detailed knowledge of every task, experience, and planning capability to predict the uncertainties. Model-based scheduling or BIM-based scheduling is a new scheduling approach in the construction industry. In BIM-based scheduling, BIM model is used as input and the computer-based algorithms collect information from the BIM model to develop the project plan and schedules. BIM four-dimensional (4D) model is an integration of the 3D model with a one-dimensional (1D) project schedule to visualize project progress graphically.

The production scheduling techniques are mostly generated from mathematical programming, operation research and optimization methods. Based on the production system, the scheduling problem may be in the form of integer linear programming, non-linear programming, or stochastic programming. The manufacturing production has a dynamic environment, and changes in the schedule are highly expected. Dynamic scheduling reflects the real-time events and unexpected changes using stochastic programming. In computer simulation approaches, artificial or historical input data are used to simulate under certain conditions and find the best schedule using simple heuristics.

2.3.3 THE INFORMATION SYSTEMS

An information system is an organized combination of hardware, software, networks, data resources, and interrelated components that collect, process, store, and distribute information in an organization. The information can be used to support forecasting, planning, control, coordination, decision making and operational activities in the organization. Manufacturing processes contain an enormous amount of information related to different sections and disparate systems. Tracking all the information from different systems will increase the productivity and eliminate unexpected delays. Some of the relevant information in the data system are the manufacturing process execution, the equipment efficiencies, the quality controls, and supply change databases. A connected data system that shares information in all the systems and links all the data sources is crucial for manufacturing productivity. Application of an efficient information system tool in manufactured construction production is necessary for the application of Lean manufacturing techniques and development of advanced tools for scheduling, planning, and material management.

The data system, stores all the information for a product from customer orders, production development, state of resources, equipment, required materials, personnel availabilities, manufacturing processes, and sale information. The data system includes real-time information, and all the data systems are linked to provide full transparency of all the production stages. Automated technologies that collect information, such as sensors for monitoring the equipment efficiency or RFID to observe material availability, are also part of the data system. Since the data system provides organized information, it will can analyze past experience and predict uncertainties in future manufacturing processes. There are several ways to apply information systems in business or decision-making operations. Data Processing Systems, Management Information Systems, Decision Support Systems and Executive Information System are some significant categories of information systems. Figure 2.20 shows an example of using information system for a manufacturing application.

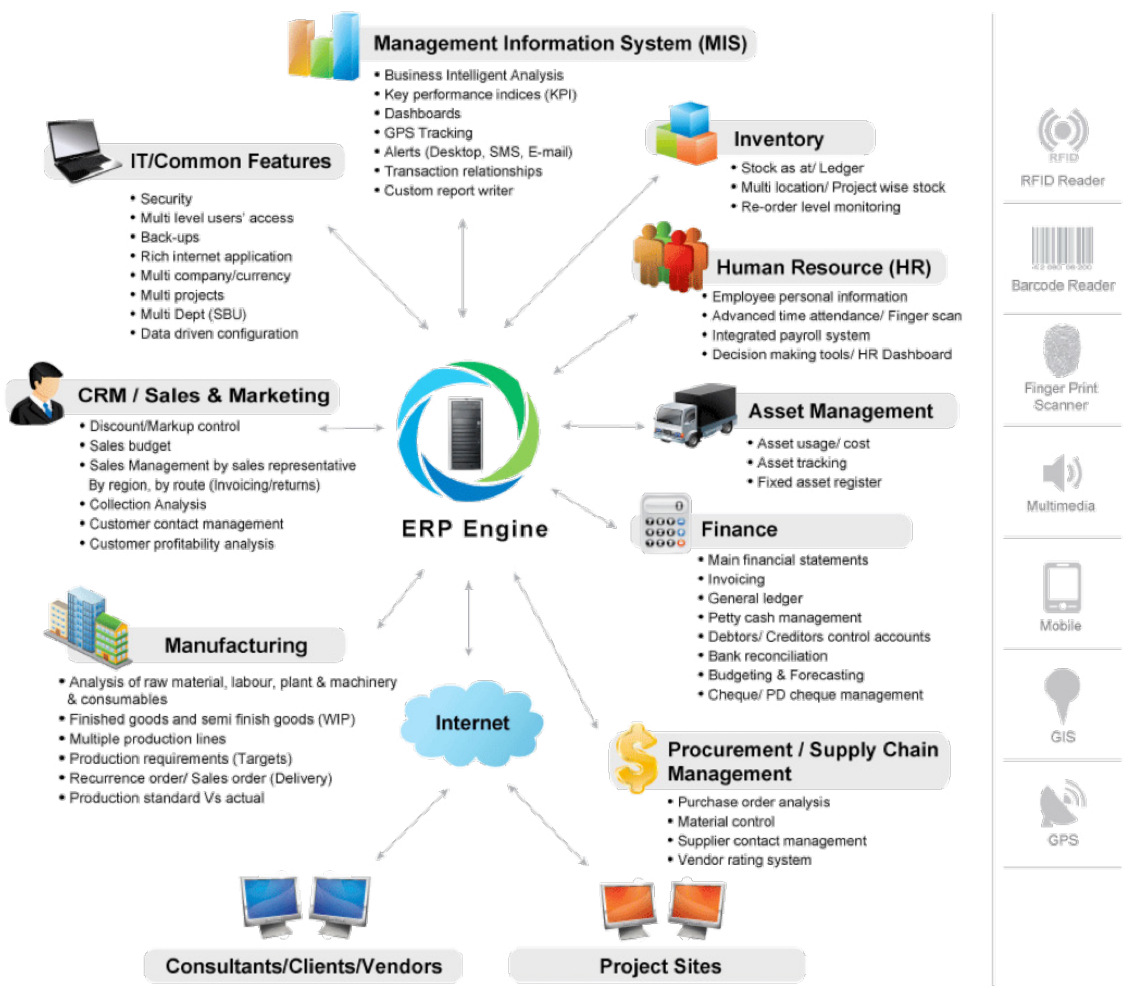


Figure 2.20 An example of information system http://www.htnsys.com/manufacturing-trading-distribution/

2.3.4 ARTIFICIAL INTELLIGENCE

Artificial intelligence is using computer machines in "cognitive" functions that are generally expected as human intelligence, such as "learning" or "problem solving". The artificial intelligence concept started as a sub-field of computer science when researchers at Carnegie-Mellon University and MIT tried to simulate human problem-solving on a computer. The problem-solving started with simple mathematical problems and developed to strategies for games like chess and checkers. The initial findings showed that computers are excellent at problem-solving and artificial intelligence science then developed extremely rapidly. Today, computer systems can perform more advanced tasks such as visual perception, speech recognition, decision-making, and control of robotics.

Artificial intelligence is applied to solve complex problems such as non-linear problems or problems with uncertain knowledge and reasoning. Generally, there are no feasible algorithms that can find an optimal solution for these kinds of problems. Local search and heuristic knowledge are applied to explore alternatives and select the best. These algorithms are based on evaluating and modifying the current solution to find a better one, rather than systematically exploring the best solution. The new trend in the artificial intelligence for problem solving is "Metaheuristic" algorithms that are based on biological or animal behavior such as simulated annealing, ant colony optimization, and genetic algorithms.

Artificial Intelligence techniques are widely applied in industries and manufacturing. Knowledge management is an application of artificial intelligence that is used to capture expertise and distribute it. Artificial Intelligence is used for complicated and multi-criteria decision making with a wide range of choices. It is very useful tool for optimizing the process planning, scheduling, and engineering design. The other main areas of artificial intelligence that are applied to manufacturing are: real-time intelligent automation, decision-support systems, metaheuristics and global optimization, knowledge processing, expert systems, neural networks, fuzzy systems, image processing, pattern recognition, vision systems, speech recognition, software engineering, Intelligent fault detection, big data analytics, complex networks, and others.

QUESTION SET 2.3

1) What is plant layout? what does plant layout include?
2) What is the equivalent of plant layout for construction projects?
3) What are different steps for site layout?
4) What does production scheduling mean? What are the important issues to consider for Scheduling?
5) What are the two classifications for scheduling? Explain each of them.
6) What is Model-based scheduling? How can BIM contribute to project scheduling?
7) What is information system? what is the purpose of using information systems in manufacturing?
8) What is artificial intelligence? what are some of the recent development in this area?
9) What is the application of Artificial Intelligence in manufacturing?

2.4
DESIGN AND INFORMATION TECHNOLOGY

After the industrial revolution, advanced equipment and machines were introduced to manufacturing processes to increase production efficiency and quality. Machines are used to perform repetitive work with the least number of deficiencies and on a larger scale. Today, many automated machines and equipment have been developed and the construction industry utilizes many advanced machine tools in construction processes. The selection of the best manufacturing process and the most appropriate technologies for each task is a complex decision that contains consideration of several factors such as desired shape and size of the product, properties of materials, quality of the manufactured product, and the cost of manufacturing. The manufactured construction industry has few applications for cutting-edge technologies in the production and manufacturing processes. This section briefly introduces some of the advanced machines that have the potential to be applied to the fabrication of manufactured homes in the future.

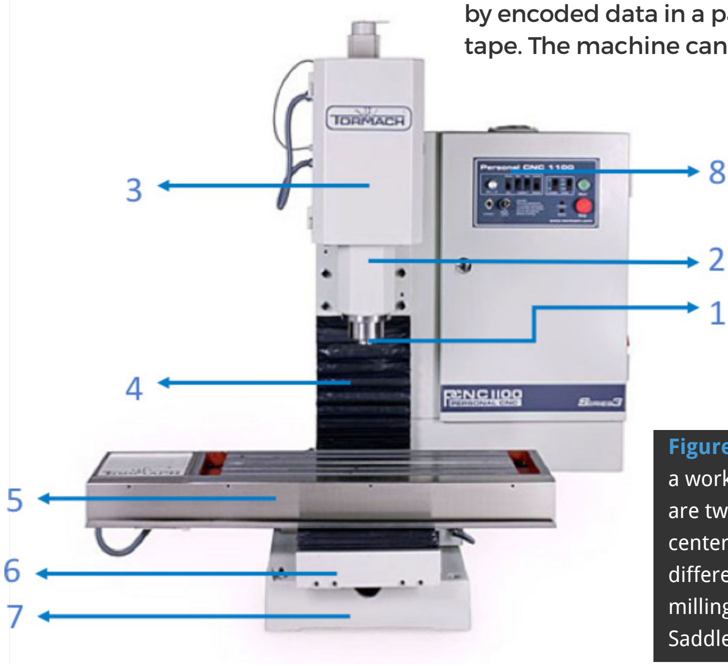


Figure 2.21 CNC Milling uses rotary cutters to remove material from a workpiece in a direction at an angle with the axis of the tool. There are two types of CNC milling machines including vertical machining centers and horizontal machining centers. The picture shows different components of a CNC milling machines including: (1) Face milling cutter, (2) Spindle, (3) Spindle head, (4) Column, (5) Table, (6) Saddle, (7) Base, and (8) Spindle switch.

2.4.1 COMPUTER NUMERICAL CONTROL (CNC) MACHINES

There are many machine tools used in manufacturing processes and building construction. The first generation of machining tools is manual machine tools such as milling machines, lathes, and drill presses. These are mechanical or electrical machines and the motions of the machine tool had to be controlled manually or mechanically. The tools must be operated by a skilled machinist who has advanced training and operator skill determines the quality of the products. As a result, using these machines was relatively slow and expensive.

Numerically controlled machines are one of the first programmable automation tools in which the process is controlled by the numbers, letters, and symbols. The machine is composed of a rigid machine base to hold the moving parts, a spindle to mount the cutting tool, and a table that can move left to right and in and out. The numerical control helps the machine to move based on the input program. The programs are loaded by encoded data in a paper or plastic tape. The machine can read the tape and execute the program.

Computer Numeric Control (CNC) is the new generation of numerically controlled machines that use a computer interface to record information and to control the device electronically and automatically. An operator or a programmer writes a set of instructions to describe the moves for the customized object. The machine is programmed with a CNC machining language (called G-code). The controller reads the instructions and adjusts all the axial movements of features like exact feed rate, coordination, location, and speeds. There are sensors that keep track of the table position and velocity to send signals to the controllers. The computer evaluates the next move and sets the table velocity and position. The new generation CNC machines can use a Computer-Aided Design (CAD) drawing (either 2D or 3D) as input and create a readable code for the machine. Computer-Aided Manufacturing (CAM) software makes the CAD drawing/design into a G-code that the CNC machine can understand. Figure 2.21 presents different components of a CNC machine and Figure 2.22 and 3.23 are two example of CNC machines.

Figure 2.22 A CNC lathe is used for precisely machining relatively hard materials with movements of rigid cutting tools, such as tool bits and drill bits in a rotating workpiece.

Figure 2.23 A CNC router is a cutting machine connected to a router used for cutting various hard materials, such as wood, composites, aluminum, steel, plastics, and foams.

The CNC machines have many advantages in manufacturing including increased productivity, better quality, and reduced cost. The high level of precision of CNC machines make the production of more complex shapes possible. The CNC machines can be applied in the building and construction industry and manufactured construction for repetitive manufacturing processes and large production of building components, such as timber oc plastic.

Custom and general cabinet manufacturing are some of the most popular applications for CNC routers. Using CNC has increased the quality and productivity of cabinet production. CNC routers are used in producing many different styles of cabinet sets, closet sets, doors, drawers, shelves, and counter tops with ease and precision. These machines also allow shops to expand their capabilities on to furniture designs such as chairs, tables, rail systems, and other various ideas. The CNC machines work in 2D or 3D axes that can drill quickly, cut more accurately, and provide a completely smooth finish.

2.4.2 LASER CUTTING MACHINES

A laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The lasing material is stimulated by electrical discharges or lamps, and the laser beam is reflected internally within a closed container. After the beam achieves sufficient energy, it will escape the container as a stream of monochromatic coherent light. Lasers have various applications in manufacturing processes and may have modified properties for their specific application. Laser applications include casting, forming, joining, and machining processes. Laser cutting is the application of laser for machining processes that is one of the major areas of laser applications in the manufacturing processes. In laser cutting machines, like CNC, a computer controller modifies the motion and geometry of the workpiece for variety of one, two, or three-dimensional machining applications.

In laser cutting, the materials are removed in a number of ways such as vaporization, melt expulsion, and chemical reactions. Several materials may produce the laser action and they are classified into four main types, based on their physical nature, including solid-state lasers, gas lasers, semiconductor lasers, and dye lasers. Two types of CO2 and Nd:YAG laser is the most common in different laser cutting machines. The CO2 is a gas laser with an excellent power input to output ratio, and the Nd:YAG is a solid state laser that uses a crystal as a lasing medium.

Laser cutting is a two-dimensional machining process in which the workpiece material is placed on the table and a highly intense laser beam is focused through a lens on the cutting lines. The laser heats the workpiece until it melts or vaporizes the material, makes a cutting front, and a high-pressure gas jet removes the molten material. The laser cutting machine moves the workpiece (or the laser beam in few cases) to make the customized cutting across the surface. They are used for a wide range of metallic materials such as steels, copper, aluminum, and brass, and nonmetallic materials such as ceramic, quartz, plastic, rubber, wood, and fabric. The laser cutting machines are available in different sizes and specifications (Figure 2.24).

Based on the procedure, there are many approaches for lasercutting machines including evaporative laser cutting, fusion cutting, reactive fusion cutting, and controlled fracture technique. The evaporative laser cutting heats the material until the vaporization point and the materials removal is due to direct phase change with high quality. This method is appropriate for the materials with low thermal conductivity such as organic materials, cloth, paper, and polymers.

In the fusion cutting, a laser beam moves through a cutting path and the energy absorption in the material leads to melting the metal. The molten material creates a thin layer of cutting front and the assist gas ejects from a nozzle, coaxial with the laser beam. Reactive or Oxygen-Assisted Laser Cutting is a type of fusion cutting with a different gas assistant process which also includes oxidation and chemical activity. This method is useful for cutting thick section of stainless steels, titanium, and aluminum alloys. Finally, in the controlled fracture technique, the laser energy creates mechanical stresses in controllable areas of the workpiece. The stress makes cracks in the material and controllable laser beam leads to fast crack propagation that includes fracture growth and crack extension. However, due to the controlled fracture technique, less energy is required in this method, and the process would be faster. This method has a good quality for brittle materials such as alumina and glass.

The laser cutting machines are a type of CNC and they are mainly controlled and operated by computer interfaces. An operator manages the computer system and enters the information into the system in the correct format. The system will configure automated movements based on the input data. Using laser cutting machines in the manufacturing processes will result in increasing productivity and producing high-quality products. The machines are flexible for complex geometries in a fast process with smooth finishes and for cutting of wide range of materials. They are automated, programmable, easy to use, and easy to set up and result in faster manufacturing and cost savings. Some of the problems in using laser cutting are remaining striations, periodic patterns, dross on the cut edges, and causing heat-affected zones.

Laser cutting approach	Principle	Material properties	Example
Vaporization	Direct vaporization of material by laser energy with inert assist gas	Low conductivity, low heat vaporization	Cloth, wood, paper, etc.
Fusion	Laser energy melts the material which is subsequently expelled by impinging inert gas jet	High conductivity materials	Nonferrous materials (titanium, aluminum, etc.)
Reactive fusion	Exothermic reaction creates additional source of energy. Molten materials is removed by reactive gas jet in the form of mixture of oxide and metal	High conductivity, reactive materials	Mild steel, titanium, stainless steel, etc.
Controlled fracture	Laser energy introduces stresses in localized area followed by mechanical or lase induced severing	Brittle materials	Alumina and other ceramics

Table 2.1 There are four main approaches used by laser cutting machines and each of them is suitable for a particular kind of application.

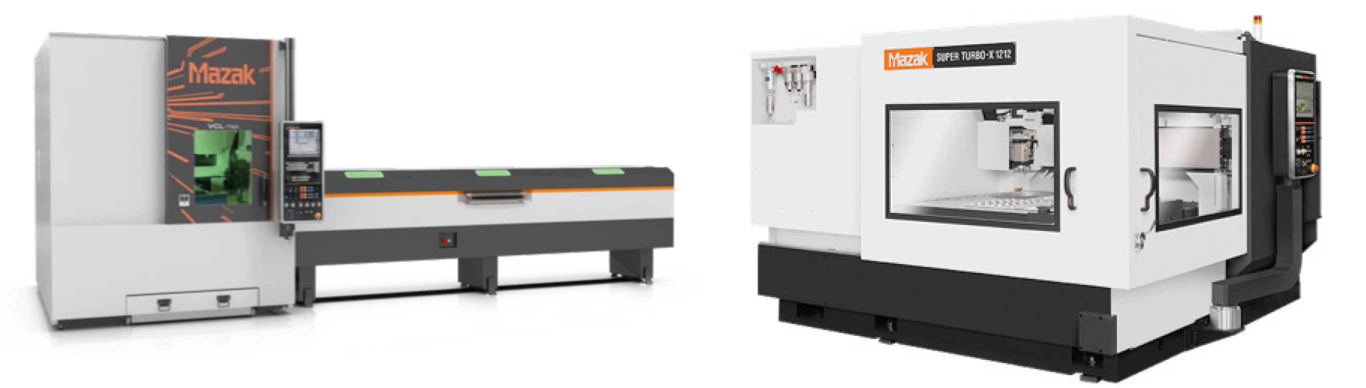


Figure 2.24 The laser cutting machines are connected to a computer controllers and they are available in different sizes and specifications.

2.4.3 3D PRINTING MACHINES

3D printing or additive manufacturing is a process for automated production of three-dimensional solid objects from a digital (CAD) input and with layer-by-layer control. Many manufacturing industries derive benefit from 3D printing technology as an automated production process. 3D printing is now being exploited by construction industry on an initial test basis to determine the feasibility for more widespread use.

There are five main types of 3D printing based on the processing technology: stereolithography, fused deposition modeling (FDM), inkjet powder printing, selective laser sintering (SLS), and contour crafting. Figures 3.25 thru 3.29 briefly describe the process for each 3D printing type and Table 3.2 shows their comparison.

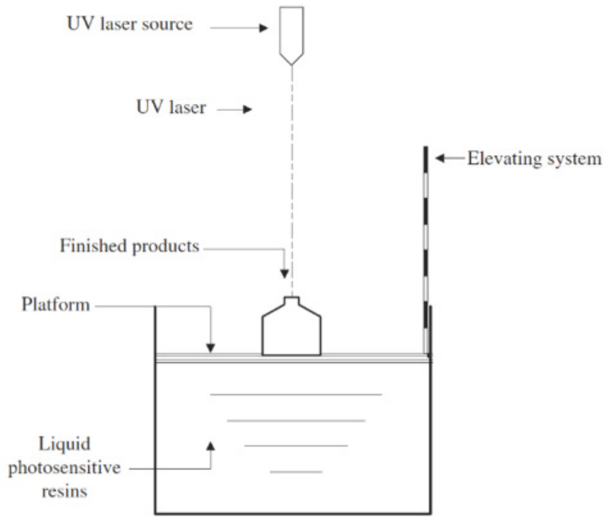


Figure 2.25 In stereolithography, a UV laser traces a liquid polymer and causes the polymer to harden. The laser beam tracks processed information of a layer from the CAD model and the same process is repeated for next layers until the 3-D model is created. Finding suitable, affordable resin materials is the main challenge for the stereolithography technology.

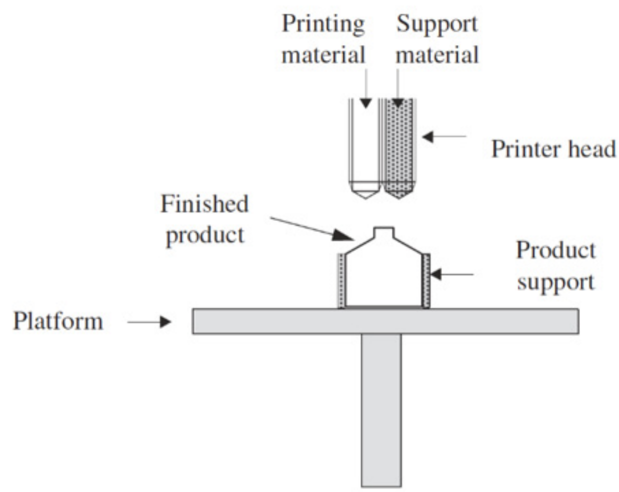


Figure 2.26 In FDM, the printing material is fed to the printing head and the printing head will move in X- and Y-coordinates based on the CAD model. The process will repeat for each layer to form the desired object and the support material will be removed later. Metals can be used as the print material in FDM but they may cause some problems due to low-strength or oxidation.

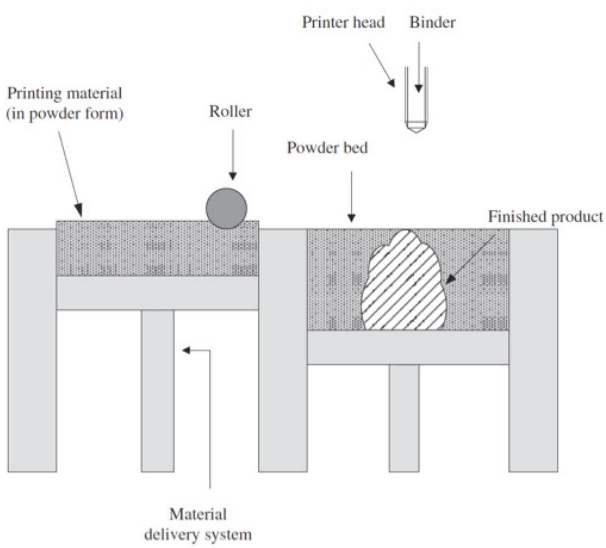


Figure 2.27 Inkjet powder printing process uses glue or binder to bond successive powder layers together. The binder material is sprayed from the printer head and is getting dry fast for each layer before bonding next layers. Metal powder are common as the printing material but finding an acceptable powder and binder with expected properties is challenging.

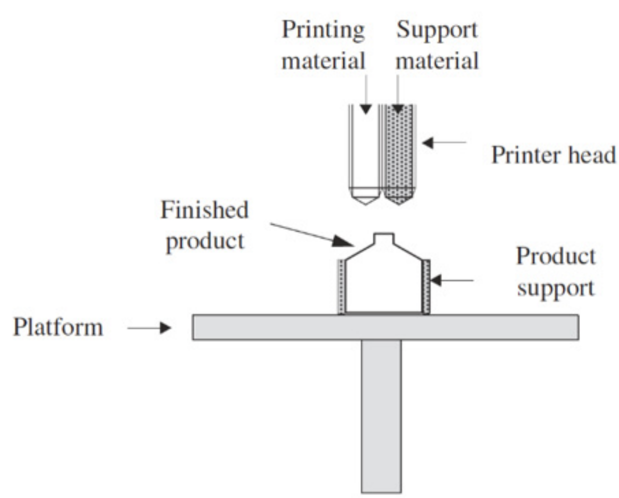
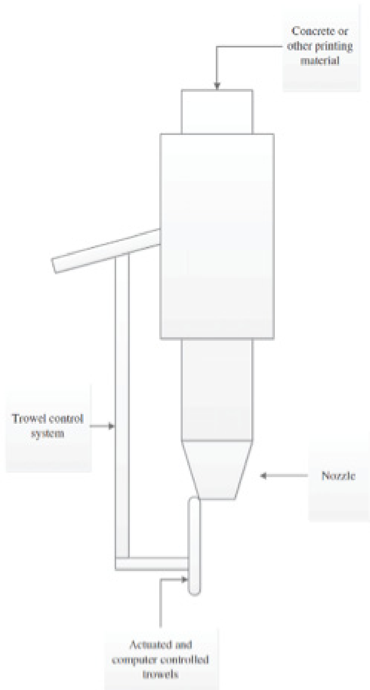


Figure 2.28 In SLS, first a laser beam melts the powder material and then layers of molten material are consolidated on top of each other to make the 3d object. SLS is good for complex geometries and usually works in small scales. For metal products, it is referred as selective laser melting (SLM) or direct metal laser sintering (DMLS).



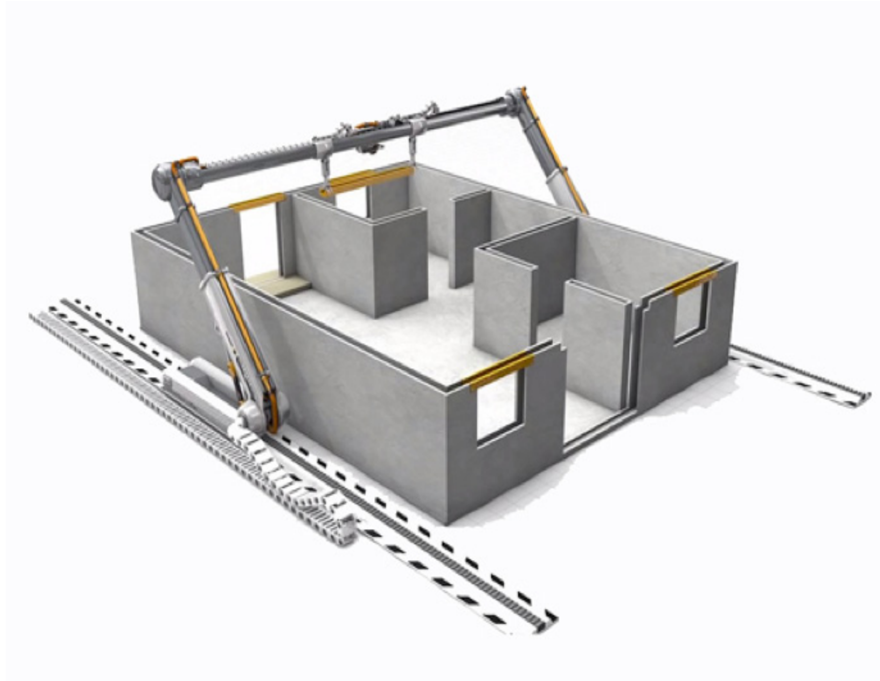


Figure 2.29 In contour crafting, the printing material extrudes from the nozzle and computer-controlled trowels form the smooth and accurate surfaces. They work like the gantry system used in precast concrete fabrication. The contour crafting is automated layered fabrication that uses concrete or ceramic materials for printing and is a useful tool for house construction with large scale 3D printers. Development of mobile 3D concrete printers to fabricate entire house is an ongoing research conducted by Dr. Khoshnevis of the University of Southern California.

3D printing technology	Components	The printing process	Printing materials
Stereolithography	• A perforated platform • A container of a liquid UV-curable polymer • A UV laser	Using a beam of UV laser to harden the liquid polymer and lower the platform to create multiple layers.	Liquid photosensitive resins
Fused deposition modeling	• A printer head • Printing material • Support material	Printing material is fed to the printer head to deposit the material to the layers.	Acrylonitrile butadiene styrene (ABS); Elastomer; Wax; Metal
Inkjet powder printing	• A printer head • Printing material in the powder form • Binder • An oven	Printing material in the powder form is deposited. Binder is then sprayed, heated and dried. The product will be cured in an oven when completed.	Polymers; metal
Selective laser sintering	• Focused laser beam • Printing material in the powder form	Printing material in the poser form is deposited. It is then consolidated using a focused laser beam. The process is repeated from layer to layer.	Nylon based materials; rapid steel; sand form
Counter crafting	• A gantry system • A nozzle • Printing material • Trowels	Printing material is extruded from the nozzle and then troweled. The gantry system s computer controlled and moves with the nozzle.	Ceramics materials; concrete

Table 2.2 3D printing technologies have specific processes with different cost, printing time, accuracy, and materials.

3D printing technology is largely implemented in small scale objects with low production rate and justifies the fabrication of 3-dimensional complex designs. However, 3D printing is a relatively new area in the construction industry. Major areas of 3D printing application in construction are for concrete printing, manufacturing of building products, and prefabricated components.

The construction industry has implemented 3-D printing in making architectural models since the early 2000s. The detailed information about each layer of the building is driven from a building 3D model and the computer programs will control the 3D printer to produce the architectural model of building. FDM, SLS, and stereolithography are 3D printing methods used for producing architectural models. Despite the accuracy of 3D printed architectural models and its fast fabrication, reproducing complex details is still very difficult. An example of using 3D printing technology to create complex architectural prototypes and models is the Sagrada Familia cathedral in Barcelona (Figure 2.30).

Prefabrication is a branch of manufactured construction in which the components of a building structure are constructed in the factory and assembled in the place. There are limited types of building components that are designed for prefabrication with standard features. 3-D printing technology allows production of more customized products and complex objects, and as a result, provides enhanced flexibility for prefabricated designs.

The current stage of 3D printing technology in construction industry is large scale printing of entire building. It can be argued that the main weakness of 3D printing is the size of the equipment required to print the large items. Printed buildings are limited in size and the printer has more expensive set up. In addition to the printer size, selecting printing materials is very important role in 3D printing. The printing materials should have some basic features such as quick hardening, strength, and stability. Several materials have been modified and proven to be effective as high-strength printing materials. 3-D printing is mainly applied for small part sizes, but industrial applications for large-scale 3-D printing have made significant progress in recent years. Figure 2.31 to Figure 2.33 show some of the recent case studies of using large scale printers for construction of the entire building. Figure 2.34 shows a large scale concrete printer developed by ROHACO Company for Eindhoven University of Technology. The printer uses counter crafting technique to print large concrete design.

Figure 2.30 The Sagrada Familia cathedral in Barcelona is the fabulous design of Antoni Gaudí, started in 1882. He could not finish more than a quarter of his project by the time of his death in 1926. Also, the blueprints of the design were destroyed during the Spanish Civil War. Due to the complex nature of Gaudí's design, recovering the missing schemes and creating visual prototypes was a time-consuming and expensive process. The team started using 3D printing since 2001 to continue the work of this great designer. 3D printing technology helped the architects to create various complex prototypes and enhanced the design process based on the Gaudi's style. The Sagrada Familia cathedral project is anticipated to be complete in 2026. {Photo Credit © Expiatory Temple of the Basílica de la Sagrada Família}

Figure 2.31 WinSun Decoration Design Engineering is an architectural company in China that uses a large dimension 3-D printer to fabricate buildings. In 2014, the company printed a group of ten houses in Shanghai in less than a day. Their printing material is a high-grade cement and glass fiber but recycled concrete was also used in few project. The picture shows a five-story apartment and a villa (approximately 1100 m2) for which the building components was printed and brought to the site for assembly.

The current stage of 3D printing technology in construction industry is large scale printing of entire building. It can be argued that the main weakness of 3D printing is the size of the equipment required to print the large items. Printed buildings are limited in size and the printer has more expensive set up. In addition to the printer size, selecting printing materials is very important role in 3D printing. The printing materials should have some basic features such as quick hardening, strength, and stability. Several materials have been modified and proven to be effective as high-strength printing materials. 3-D printing is mainly applied for small part sizes, but industrial applications for large-scale 3-D printing have made significant progress in recent years. Figure 2.31 to Figure 2.33 show some of the recent case studies of using large scale printers for construction of the entire building. Figure 2.34 shows a large scale concrete printer developed by ROHACO Company for Eindhoven University of Technology. The printer uses counter crafting technique to print large concrete design.

The process of 3D printing contains development of digital model, exporting the information to the controller, and printing the model. Some computer applications were used to convert 3D model of buildings to the digital model for 3-D printing. A BIM model can be used as input for the 3-D printing of small-scale models and large-scale buildings. BIM is a powerful tool in complex building design and 3-D printing technology make production of complex geometries possible. Interaction between BIM and 3-D printing improves the ability to design and fabricate complex projects rapidly and efficiently. Besides, BIM is an object-oriented model in which the design process is component-based. So, BIM is known as an efficient tool to improve design for fabrication. In addition, using 3D printing allows the producers to fabricate components piece-by-piece

Figure 2.32 Qingdao Unique Technology in china introduced a large 3-D printer of a size about 12×12×12m in 2014. The printer uses the FDM technology and glass reinforced plastic as the printing material. It was used for printing an entire building of "Temple of Heaven" with 100 m2 area and around 20 tons of material.

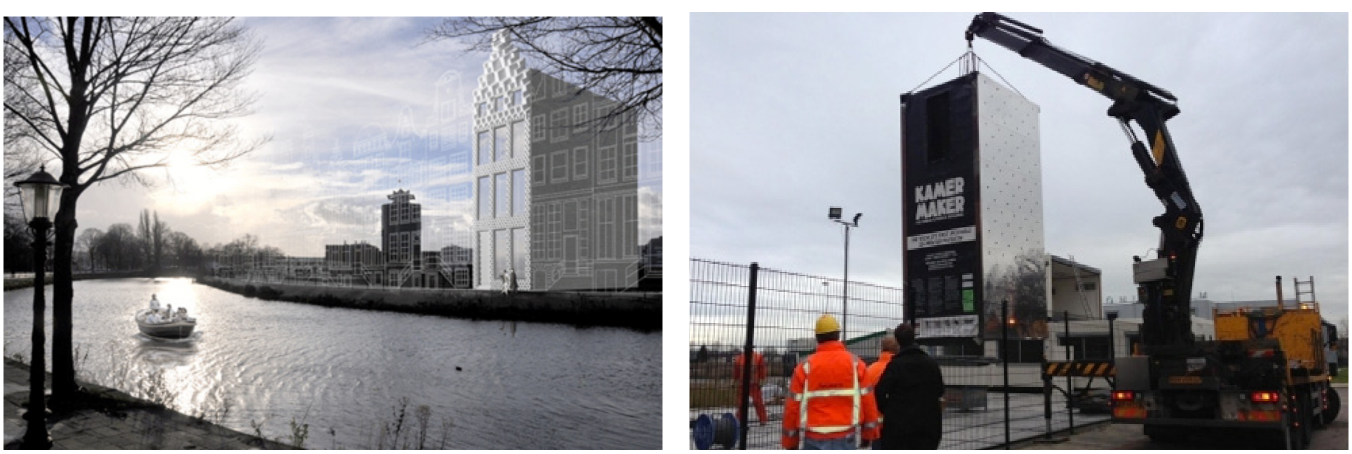


Figure 2.32 DUS Architects is an Amsterdam-based company that developed a large 3-D printer of 6m tall (KamerMaker) o fabricate a canal house. The 3D printer can fabricate components with dimensions of up to 2.2×2.2×3.5m and uses polypropylene as the printing material. The components of the canal house were fabricated in the factory and installed on site later. The project is expected to be completed in 2017. The picture shows the 3D printer and the model of canal house.

and then assemble them. By using 3D printing and BIM integration, the fabrication methods and design features can be customized for each component. Most BIM models support exporting to a file in proper format (i.e. Standard Tessellation Language format) that can be directly converted into a set of instructions for printing.

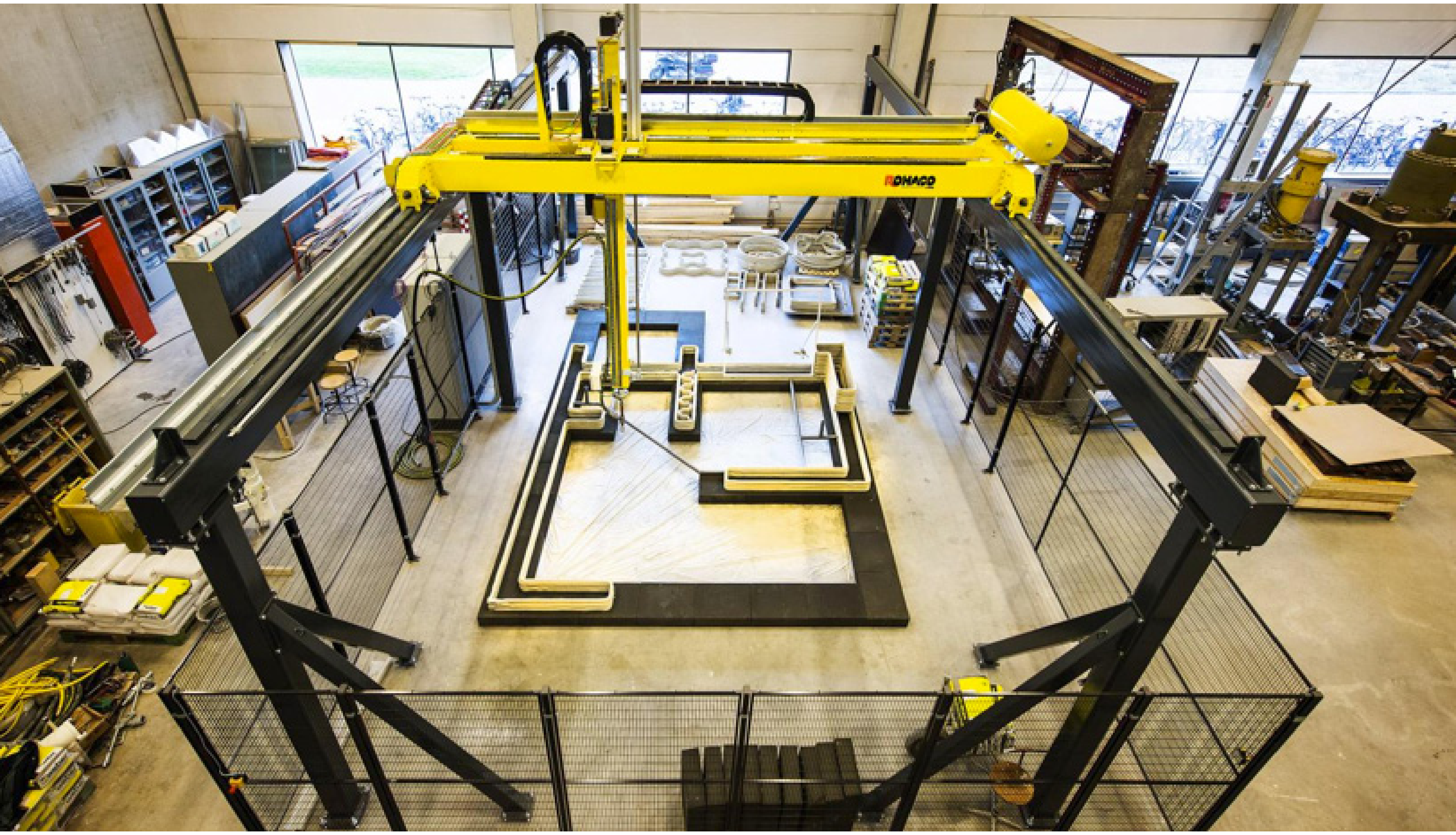


Figure 2.34 Eindhoven University of Technology started using a concrete printer that enables printing objects of up to 11 meters long, 5 meters wide, and 4 meters high. The concrete printer is the first kind with large dimensions in the Netherlands, developed by the ROHACO Company.

Although 3D printing may offer many benefits to the manufactured construction, there are few application, especially in manufactured houses. One of the major benefits of 3D printing for manufactured housing is increasing the flexibility of design. Design customization, based on the costumers' desire, is a key marketing tool in house-building sector. Bringing integration of BIM and 3D printing into the manufactured housing, will significantly increase mass customization. In a nutshell, benefits of 3D printing for manufactured construction are productivity improvement, reduced waste, design flexibility, reduced manpower, and many other economic, environmental, and constructability-related improvements.

2.4.4 ROBOTICS

Robotics is a branch of mechanical engineering, electrical engineering, and computer science that deals with design and development of automated machines (robots) to improve the efficiency of activities in one's personal life or, at a larger scale, for manufacturing processes. A robot is any mechanical device that is capable of performing a variety of often complex human tasks on command or by being programmed in advance. Some of the robots resemble a human body and are known as humanoid robots. The Robot Institute of America, in 1979 defined robot as:

"A re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks."

The concept of producing automated and programmable robots started in the 20th century. The first digitally operated robot was developed in 1961 for lifting hot pieces of metal from a casting machine and stack them. Robotics technology has rapidly advanced and robots can function in dangerous environments, perform repetitive works, and carry heavy loads. Today, commercial and industrial robots have extensive applications in making activities cheaper, more accurate, and more reliable. Some other applications of robotic technology are manufacturing, picking and packaging, inspecting products, assembly, transport, earth and space exploration, surgery, weaponry, safety, and laboratory research. Robots that are designed and programmed to perform specific manufacturing tasks are known as industrial robots.

Although there are many types of robots, all of them have the basic features of sensing, dexterity, memory, and trainability. The mechanical structure of a robot is designed to execute a particular task. The design should consider the working conditions and physical limitations to make the robot mechanically capable of completing the assigned task. Robots have an electrical controller to provide power and control the movements. In addition, all robots include some level of computer programming to manage the automated movement and control options. Robotic programs have three types of control: remote control, artificial intelligence, and hybrid. Robots with remote control programing will only act according to the signal from a control source or a remote control. A robot with artificial intelligence will interact with the environment to receive information and determine reactions to the objects and problems. Hybrid robots incorporate both programming systems.

Robots are composed of many components that require a complex design based on multidisciplinary knowledge. The controlling mechanism of a robot includes perception, processing, and action. The sensors will collect information about the robot and its surrounding environment (perception). The information is transmitted to a computer processing unit and the appropriate signals for next movement is calculated (processing). Finally, the actuators receive the signals and move the mechanical structure (action). The main components of a robotic system include:

- **Power source:** Robots need a power supply and energy storage to provide energy for its operation. The power source for a robot depends on its application. An electrical power source with batteries is the most common type of power source.
- **Manipulation:** Robot manipulator is also referred as the "arm" or the "hands" of robot that is the dynamic system of the robot. The manipulator is composed of some joints and links that can be controlled within three-dimensional space and make linear or rotational movements. The working area is the space that can be reached by the end of the robotic arm. Advanced robots have arms capable of moving in several axes that increase their working area (Figure 2.35). Based on the robot application, different tools may be installed at the end of the robotic arm. Some of the common end-of-arm tools are clamps, welding guns, electromagnets, suction pads, hooks or paws, etc.
- **Motion:** Some robots use motion tools like wheels or legs to move in the surrounding environment.
- **Controller:** Robots has a computerized digital controller to run the programming and artificial intelligence. The industrial robots are typically linked to a computer for programming.
- **Actuators:** Actuators are the "muscles" of a robot that convert the stored energy into movement by controlling all the axes and the direction of moving.
- **Feedback system (Sensors):** Sensors will help the robot to be intelligent by identifying the position of each axis, moving velocity and acceleration. Different types of sensors are used in the robots based on their application. The most common ones are vision (light), touch, sonar, chemical, and radar sensors.

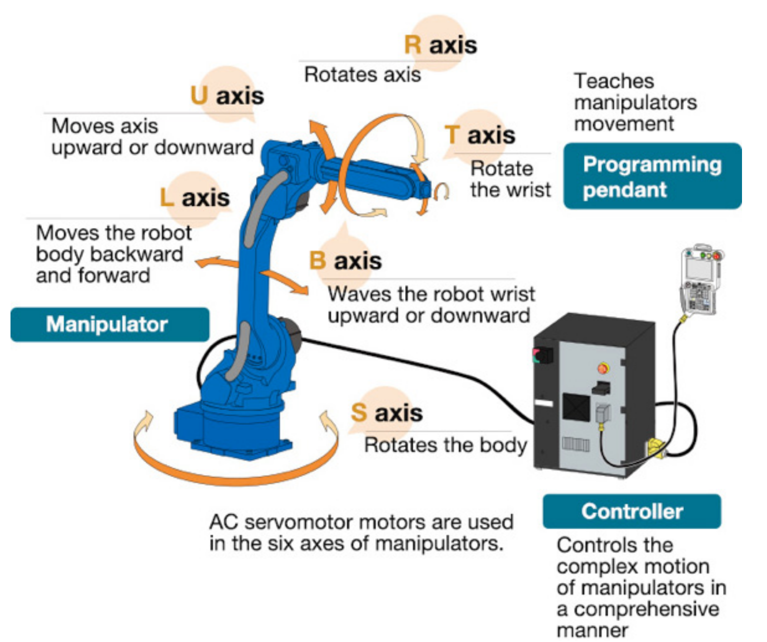


Figure 2.35 Arm robots are able to move in different axes. More advanced robots have more axes that increase their working area.

Robots are widely used in manufacturing processes and they can improve the productivity and efficiency of production. The automotive industry is one of the largest users of robotic technology and it is very common to see robotic systems in a car manufacturing factory. Typical applications of robots in industry include welding, painting, assembly, pick and place for printed circuit boards, packaging and labeling, palletizing, product inspection, and testing. Figure 2.36 represents worldwide annual supply of industrial robotic in the main manufacturing industries.

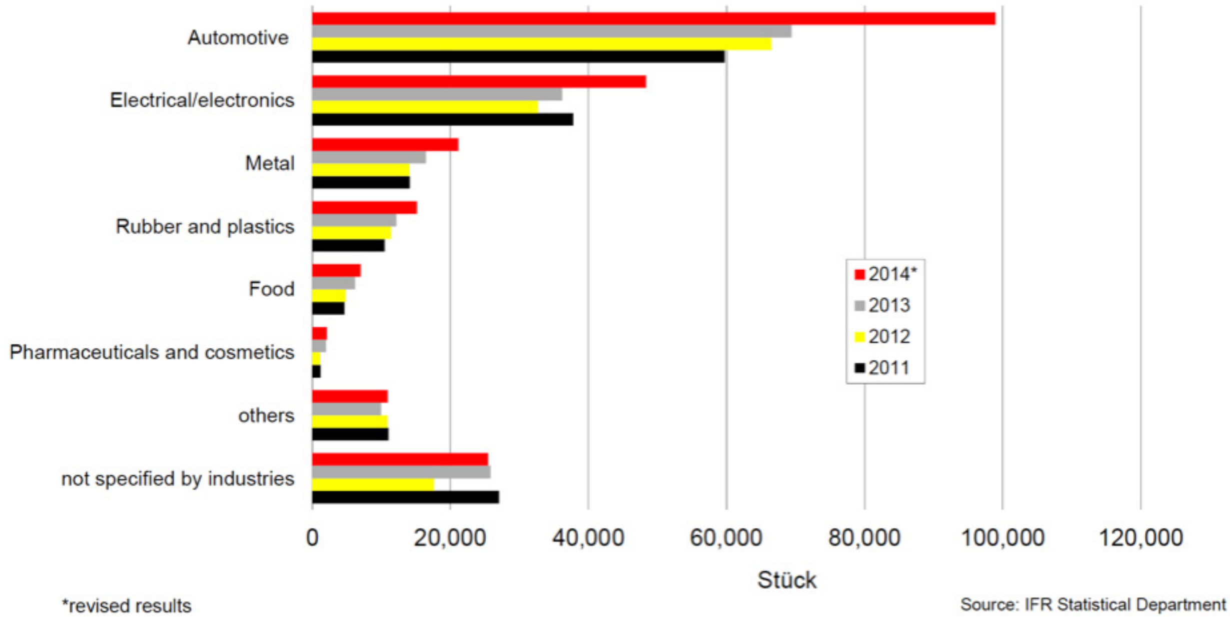


Figure 2.36 The worldwide annual number of industrial robots and their applications are increasing in the main industries.

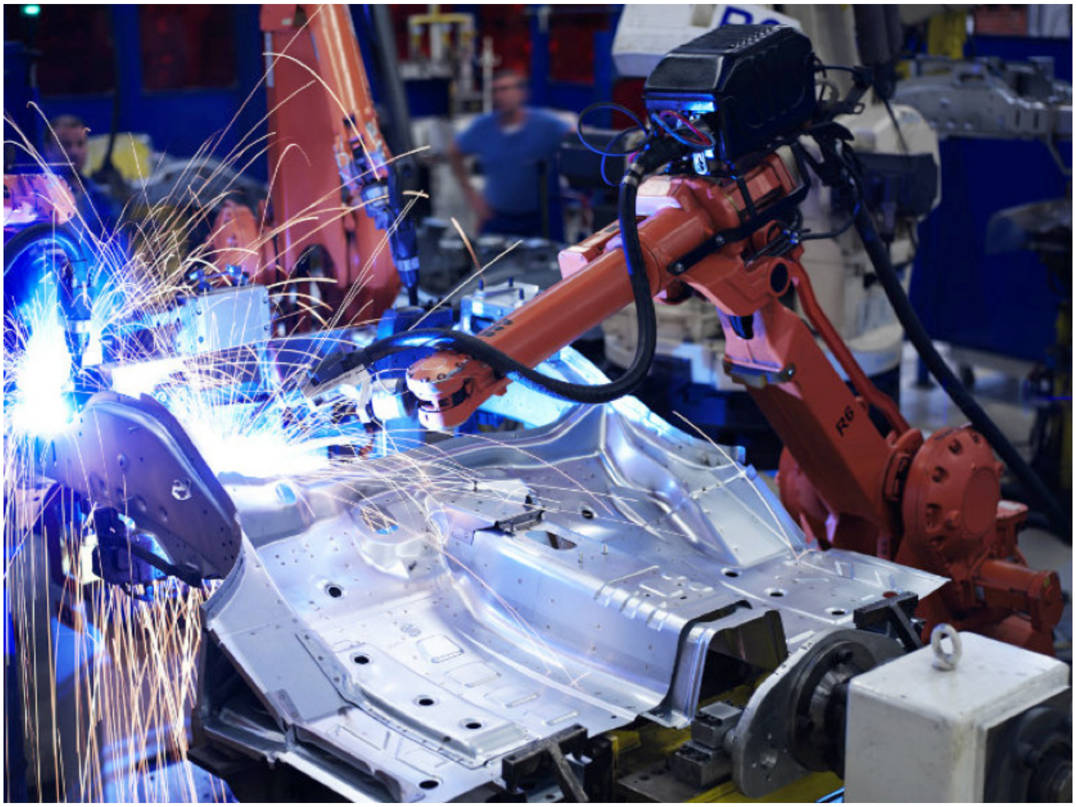


Figure 2.37 Robots are commonly used for spot welding and arc welding in the automotive industry.

Figure 2.38 Robots handle materials for many manufacturing processes. By using specific end-arm-tool, the robot may be able to do tasks like holding, picking and packing, transferring, and bending of components or materials (http://www.fanuc.eu/)

Robots are produced in different types and are often classified based on their application. For example, robots that are designed for assembly work are classified as assembly robots. Welding robots can provide complete welding systems including arc welding and spot welding. Heavy duty robots are specifically designed for carrying heavy loads in the production line. Some robots are designed to carry out repetitive actions and with a high accuracy. Other robots are more flexible in knowing the surrounding environment, identifying the objects, and then performing the assigned task. The manufacturing production line usually includes several types of robotic technologies that work in sequence with the production team.

Another benefit of using robots is increased safety and the elimination of human labor in hazardous areas. For example, robots can be used to load and unload cutting tools to increase safety for the worker. Cast treatment robots are used for molding processes in the metal melting process to eliminate the risk of any accident or injury. Painting robots provide high-quality spray painting that finishes surfaces for many products. Using robot painting can eliminate the health issues related to volatile organic compounds (VOCs) in the paints and increase air quality for the worker. Figure 2.37 to 3.39 represent examples of robotic application in manufacturing processes.

Figure 2.39 Robotic application in the production line of an automotive factory. In this picture, several robots are working together and in a sequence to build automobiles.

Table 3.3 Major developments in robotics occured in the second half of 20th century. Some of the main robotic developer companies are Yaskawa Motoman, FANUC, KUKA, ABB, and Robotic Workcells.

Year	Title	Inventor	Describe
1960	Versatran	Designed by Harry Johnson and Veljko Milenkovic Manufactured and marketed by AMF Corporation	
1962	UNIMATE	Manufactured by Unimation	The first industrial robot to be used by a major manufacturer. It was installed by General Motors in its New Jersey plant.
1973	Famulus	Developed by German robotics company KUKA	Had six electromechanically-driven axes.
1974	The Silver Arm	Developed by Prof. Victor Scheinman Manufactured by Vicarm Inc. Founded by Scheinman	Performing small-parts assembly jobs using feedback from touch and pressure sensors and controlled by a minicomputer.
1975	ASEA IRB	Built by a European company called ASEA	The world's first fully electrically driven robot with microprocessor-controlled robot and used Intel's first chipset.
1977	Motoman L10	Developed by Yaskawa America Inc.	Had five axes and was able to move 10kg of weight with its gripper.
1978	PUMA	Designed by Prof. Victor Scheinman Developed by Vicarm, Unimation Support from General Motors	A robot arm that was used in assembly lines and is still used by researchers today.
1979		Nachi Robotics of Japan	The first servo gun technology robot for spot welding.
1979		OTC Japan	The first generation of dedicated arc welding robots.
1981		Takeo Kanade	The first robotic arm with motors installed directly into the joints of its arm that made it faster and more accurate.
1988	Motoman ERC control system	Yaskawa America Inc.	The ability to control up to 12 axes. A prototype of the first intelligent robot. The ability to control up to 21 axes that could synchronize the motions of two robots.
1992		FANUC Robotics Corporation	The ability to control up to 27 axes that gave it the ability to synchronize the motions of three to four robots.
1994	Motoman ERC control system	Yaskawa America Inc	A simpler robot arm that was more easily accessible for repair and maintenance.
1998	Motoman XRC controller	Yaskawa America Inc.	The ability to control up to 27 axes that gave it the ability to synchronize the motions of three to four robots.
1998	The Motoman UP series	Yaskawa America Inc.	A simpler robot arm that was more easily accessible for repair and maintenance.
2003	The Almega AX series	Introduced by OTC DAIHEN	A line of arc welding and handling robots.

Robotic systems are new to construction industry and are increasingly being used for advancing construction productivity. Robots already have vast application in manufacturing construction products and components. Robotics have been applied in a few manufactured construction factories, mostly in the production of prefabricated components for modular housing. For example, gantry type robots are used in some of concrete prefabrication factories to distribute concrete based on a CAD layout plan. Figure 2.40 and Figure 2.41 show Sekisui and Toyota home factories, two of the most advanced manufactured housing factories in Japan, that benefit from robotic technologies. Construction robots are rarely used on the construction job site but the application of robotics onsite is expected in the near future (such as building construction machinery, arc welding metal components, applying adhesives, and assembling doors and windows).

Figure 2.40 Sekisui is the market leader in factory-built residential housing in Japan. In 1971, they made one of the world's first modular houses, "Sekisui Heim", mostly built in the factory. In 2011, they launched the new generation of Sekisui Heim house, "Smart Heim", with built-in Sekisui Heim solar energy generation systems, high levels of insulation, and advanced energy efficiency. In 2013, they completed a Thai modular house factory with annual production capacity of 1,000 Smart Heim houses. The Thai factory is one of the most advanced factories for manufactured construction with widespread use of robotic technology in its manufacturing processes.

Figure 2.41 Toyota Motor Co., Ltd. started its housing business since 1975 in Japan. They implemented different building techniques as well as lean thinking and manufacturing techniques from automobile production, into manufacturing house units. Toyota Homes are constructed in three factories in Japan including Kasugai, Tochigi, and Yamanashi. Recently, Toyota homes started offering smart houses with high energy efficiency and solar energy generation systems.

Assembly robots are often used in the construction industry to haul and reposition large building components such as steel beams, precast concrete objects, and partially assembled building components. These robots are configured as robotic arms that are capable of carrying large and heavy loads. They usually act similar to existing construction equipment such as cranes, excavators, and concrete pumps. Based on the type of components that will be handled, different types of grippers are used, such as finger hooks, magnetic grippers, vacuum grippers, or pipe grippers. The assembly robots may have automated control using preprogramming or may need human assistance and remote controlling. However, they are able to attach the loads without human assistance using self-attaching grippers. More sophisticated controller would be able to locate, identify, and lift loads without human assistance. The robots may have wheels or tracks to move in the workspace under direct human control. Some example of existing assembly robots in construction are extended multi joint robots, steel erection robots, concrete distribution robots, reinforcement steel placement robots, and masonry construction robots. Figure 2.42 shows four assembly robots that are used for wall surfaces, pavements, and masonry construction.

Robots are capable of performing interior finishing operations like painting, plastering, fireproofing, and jointing. These robots are programmed for specific operations with high accuracy and precision. The size of the robot's manipulator arm and work envelope determines the dimensions of the interior space and its productivity. Common end-arm tools for interior work include welding guns, paint spray guns, grippers, nail guns, and caulking dispensers. Using advanced artificial intelligence for control systems will make the robots fully automated. Some of the existing robots for interior work are fireproofing robots, painting robot, wall board robots, and interior partition robots.

Another common application of robotics in construction is for finishing surfaces. There are already some robots used for continuous finishing operations over large vertical surfaces and large horizontal surfaces. They are known as floor finishing robots and wall finishing robots. Floor finishing operations include troweling, sanding, grinding, smoothing, and joint filling. Floor finishing robots should navigate the robot through its preprogrammed route and the robot must have anti-collision sensors. Typical operations for wall finishing are painting, jointing, plastering, and wall inspection. These robots should have some freedom of movement in the horizontal and vertical. For vertical finishes, robots typically finish each strip and then move horizontally to the next strip. Concrete screed robots, concrete finishing robots, spray application robots, and exterior wall inspection robots are existing technologies for finishing surfaces.

Smart construction equipment is a robotic technology that is used on construction sites. The smart construction package includes robotic bulldozers or robo-bulldozers that are led by drones. Komatsu Ltd. and Skycatch Inc. developed smart construction equipment to increase the construction productivity and reduce human resources. The robotic vehicles scoop rock and push dirt without a human behind the wheel. The vehicles are guided by data sent from drones. The drones fly over the construction site while taking pictures of the ground. Software then stitches these pictures into 3D maps. The information for the site plan and construction is added to the 3D maps and the earthworks are calculated simultaneously. Then, the tasks are set for robots on the jobsite. The drones fly over the jobsite and update the data in real time and update the equipment information. Using Skycatch drones, dramatically reduced the margin of error (20 to 30%) while noticeably cutting the time it takes to complete a sitemap (from 2 or 3 days to around 30 minutes).

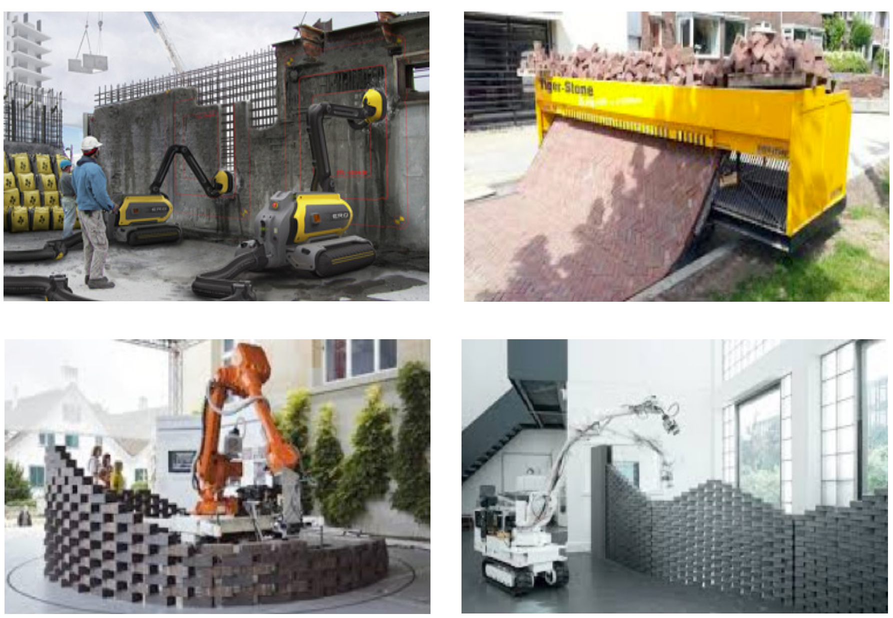


Figure 2.41 Construction robotic systems are used for wall surfaces, pavements, and masonry construction.

QUESTION SET 2.4

1) What is a Numerical Control machine and How it works?
2) How can computer be used for controlling Numeric Control machines?
3) What are the benefits of using CNC machines for cabinet manufacturing?
4) What does LASER stands for? how is laser produced?
5) What is classification of lasing materials? What are the mostly used materials in Laser cutting machines?
6) How does a laser cutting machine work?
7) What is the definition of 3D printing? What is its application in construction industry?
8) what are the limitations of using 3D printing in construction?
9) What is a Robot?
10) How does the controlling mechanism of a robot work?
11) What are the main components of a robot? Explain the function of each component.
12) How is robotics applied in manufacturing industry?
13) What are the main applications in construction?

2.5 VIRTUAL REALITY AND SIMULATION

Construction industry is continuously improving due to technological advances. These advancements are required to move the industry towards a higher level of performance. With every advance there is a need for educating the construction workforce and professionals to keep them updated on technological developments. Virtual Reality (VR) is a technology that can be used to resolve the intricate problems ingrained in a construction projects before starting the physical construction.

Virtual reality is the computer generated simulation of a three-dimensional image or environment which can be interacted using special electronic equipment by a person and seems real or physical, but the environment or picture is created in a virtual environment. The device can look like a helmet or eye glasses in an enclosed box and the user has to wear them in order to experience it. The environment or picture will seem totally real to the user and the user can be compelled to make a physical interaction as if the object or environment is real.

2.5.1 SIMULATING PRODUCTION, TRANSPORTATION HANDLING, AND ASSEMBLY OF COMPONENTS

Simulation of different activities in manufactured construction is very important. Successive activities are very much dependent on the precedent event for workability of schedule as one of the key benefits of manufactured construction is to deliver the finished structure in a very short time. Virtual Prototyping (VP) can be a good way to benefit the process by creating a prototype of the project and synchronizing it with the construction activities to obtain results. Virtual prototyping is a computer aided design process used to produce digital product models and realistic graphical simulations to generate physical layout of operations, operational concept, functional specifications, and dynamics analysis under various operating environments. Running a four-dimensional project prototype using such a system can provide a good insight of the project resulting in alternative schedules, production strategies, stages of construction and clash detections of different services and operations.

Advancements in virtual reality (VR) have made it feasible to directly utilize VR for the modeling and realization of virtual manufacturing environments. At very early stages virtual prototyping can be used for production of components for manufactured construction. It can be used to design and/or prototype a module for modular construction projects. The Distributed Interactive Virtual Environment (DIVE) package is one such example. DIVE is a system in which prototypes of the object can initiate a project planning process.

2.5.2 "WHAT IF" ANALYSIS OF DIFFERENT CONSTRUCTION METHODS

There are many different construction methods relating to onsite and off-site construction.

Many times using a particular construction technique may or may not prove to be very efficient for a particular kind of project. Virtual reality can be a technology that can help find the most efficient solution at the decision stage. Interactive situational simulation is one such technique relating to virtual programming. "Situational simulation is a part machine (computer software/hardware) and part human environment. The machine is responsible for simulating the environment using construction domain specific knowledge while being sensitive to how human participants react to it." The system thus is based on given level of detailing and can produce a number of alternative solution to a problem. The evolution of simulation of a project depends on the reactions of the human participant and the scenarios generated by the machine in reaction. For example, in situations that require labor to overwork, the produced work is lower in quality and thus the system would consider it a "re-work" event. Therefore, every time there is a delay or the human participant tries to crash activities by making labor work over time, the system considers the work lower in quality. The human participant is expected to finish the simulated project within time and budget constraints as they would in real life. Thus, their responsibility is to constantly make challenging decisions regarding resource allocation and time-cost trade-offs. As the simulation proceeds, there are a large number of ways to complete the simulated project.

2.5.3 SIMULATION SEQUENCE OF ACTIVITIES

Current working practices for construction site managers mainly rely on intuition, imagination and their knowledge of construction activities. Computerized planning and scheduling tools that are available in market for commercial use are for calculating different stages of the task and do not support conceptual planning and display the information as network and Gantt charts. These do not effectively communicate the spatial and temporal aspects of a construction schedule and thus, makes validation and communication to project partners difficult and prone to error. A visualization tool could assist the site manager in obtaining a better perception of the project. A schedule management of the project can be integrated with an animated 4D prototype of a project. This will help in sequencing of activities throughout the project. The computer generated prototype, when updated with clash detections or activity overlap, will update the schedule or activity sequence immediately. It will also be possible for the system to generate an alternative schedule if there is any kind of delay in the project such as, delay in a component delivery.

2.5.4 CASE STUDY

This case study will present work conducted within the FutureHome project. It is a 5 million Euro project funded by European Union under the Intelligent Manufacturing Systems (IMS) programme. The vision of FutureHome is to develop adaptable and sustainable building system concepts that can take advantage of advanced manufacturing systems and methods. It is promoting the use of prefabricated parts and assemblies, and developing the tools for design, configuration, production and assembly. Off and on site production and assembly processes are being developed, that can be heavily dependent on the use of intelligent automation and an IT infrastructure involving agent technology. Overall, the FutureHome project intends to produce leaner design and construction processes that will focus on value for money, improved productivity, maintainability and sustainability. The projections of benefits from the project are estimated at 30% in the cost of construction, 35% in construction time and a reduction of 60% in the number of defects. As part of this research a virtual design, construction and scheduling environment has been implemented that allows a model of a house to be constructed from a library of prefabricated components defined within the FutureHome project. The construction of the model requires minimal user interaction as the environment supports automatic constraint recognition between the components, so that as the user is constructing their model the system automatically detects whether the components the user is manipulating can be linked. An object database has been designed that holds the types of modules that are used in the building and relevant information pertaining to that component, such as price, size, construction methods, etc. As the user constructs the building, the construction information is also stored within the object database along with the order of construction and any dependencies between the tasks. It also allows the users to review the building that they have constructed from within the virtual environment, and the construction order of the 3-D model can be replayed to provide an animated 4-D model of the construction process combined with virtual machines, such as a crane, to simulate the construction process. Using Microsoft Project, the construction schedule of the project can be altered and fed back into the virtual construction environment to explore alternative construction schedules. The database also holds information relating to the construction site, such as stock, resources and delivery information.

QUESTION SET 2.4

1) What is the concept of virtual reality?
2) What is the application of virtual prototyping in the construction industry?
3) How is virtual reality used in design and planning?
4) What is Interactive situational simulation? What is the function of human participants in the simulation?

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