# Developing a System for Health and Safety Enhancement and Automation in Construction Sites

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# ABSTRACT

The construction industry forms an important element within the economic activities and is known to be challenging and dangerous. Erroneously construction site accidents were accepted as unavoidable. The existing work health and safety protocols goals were not to cut risk but to provide risk assessment by understanding the types of risks associated with various activities and setting out rules and procedures to manage them and cut their impact. This study attempts a proactive approach to construction site health and safety by anticipating the hazards associated with a planned daily work activity and providing on site the relevant training and safety instructions. This was achieved by integrating the project's digital design with site images processing and analysis. Digital image processing applies signal processing algorithms to images and videos resulting in extracting useful information from them. An essential and critical issue in the field of computer vision is the object's recognition methods which should be capable of finding the partial occlusion of objects. Knowledge management systems archive and locate the required information and make it available to the relevant destination quickly and efficiently. It can also provide access to information in other construction sites and to the design team. This management system helps to save the gained experience and make it available to the project or other similar projects. The Building Information System was introduced as a system in which the objectives of this study can be incorporated leaving the door open to incorporate other project management activities. The possible solutions for the identified health and safety business problem were analysed in order to arrive at the best solution suitable to the objectives of the study. The end users 'needs obtained from the distributed questionnaire and the project's functional requirements were considered in order to create a model that will achieve their goals in an efficient manner. An activity diagram and a user case diagram based on the UML language were generated. Based on them a computerized model (CONSTRUCTION AUTOMATA) was developed to identify risks associated with specific work activities and provide the relevant safety instructions and training to mitigate them. The model automatically produces safety reports to record and serve as a knowledge management base for future reference thus eliminating possible human errors. The computer program was tested with available site images from an existing project and it proved to deliver its outputs according to its design. The developed model was then demonstrated to a selected group of relevant professionals and was seen to score well with ease of use mark of (6.17) and effectiveness as a health and safety tool mark of (6.37) out of a total mark of (10).

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# Chapter 1–Introduction

This chapter introduces the research work presented in this thesis. It describes the background, aim, objectives and limitations of the research, and provides a guide to the content of the thesis.

## 1.1 Background

The construction industry constitutes an important element of the country's economic activities. However, it is known to be challenging and dangerous. The number of fatalities and injuries suffered in construction sites is alarming and requires a high level of attention.

A false belief exists that due to the dangerous nature of the construction site; worker's accidents are expected and accepted. The type of hazards which the workers are exposed to vary from physical injuries, ill health, or fatality resulting from the nature of the work being conducted such as electrocution, falling off scaffolds, ladders, and roof works, and falling in ditches and excavation works (Hamid et al. 2003).

Erroneously in the traditional construction industry, construction site accidents were accepted as unavoidable. Workers in the construction industry have two to three times higher probability to die on construction site jobs and the risk factor of serious injury is almost three-fold compared to other industries. These facts highlighted the need for consistent excellence in worker safety demands by all parties engaged in construction-related activities.

Furthermore, at the construction site, the workers are exposed to various hazardous substances and physical agents such as silica dust, asbestos, lead, sewer gasses, organic solvents, radiation, welding fumes, noise, and vibration. The consequences of excessive exposures may result in serious illnesses, injuries, temporary or permanent partial disability, or even death. The risks resulting from these factors are escalated when workers are working under fatigue or poor health conditions.

The nature of construction works characterized by a high number of workers in a congested work site conducting different types of works simultaneously and managed by several subcontractors is a recipe for accidents and hazards (Hughes and Ferrett, 2004).

The objectives of work health and safety protocols are not to eliminate risk, which exists with every type of activity or business. Their objective is to understand the types of risks associated with various activities and set out rules and procedures to manage them and reduce their impact. This exercise is known as ‘risk assessment’.

All businesses are compelled to follow the related regulations imposed by the law. However, priorities can be assigned to the implementation of these regulations by defining and concentrating on major subjects and avoiding wasting time and efforts on secondary issues (Health and Safety Executive, 2006).

There are two major categories of hazard encountered in construction sites which are either physical or health related (Hamid et al., 2003):

1. The risk or hazard of physical injury:

These types of hazards are associated with the nature of the job or operating the equipment required for the job. An example of jobs that may result in a physical injury is scaffolding, and working at high elevations such as in roofs or ladders. Working with hazardous equipment as in excavation or machinery operation is another example. These hazards result in a direct physical on-site injury or death if they are of a severe nature.

2. The risk of ill health or health hazard:

Health issues in construction work may result from exposure to physical, chemical, and biological hazards**.** The results of these hazards of ill health may only be noticed after time which can be rather long in certain circumstances.

Three basic rules must be followed to ensure safe working conditions which are hazard identification, hazard assessment, and hazard risk control (Hamid et al., 2003).

The gathered facts and evidence, Holt (2005) indicates that construction is indeed a very dangerous industry which may lead to the assumption that the industry is not truly adhering to the related safety rules and regulations. While this may be partly true, the construction industry is known to be one of the most dangerous and hazardous industries and its safety measures are complex being influenced by several factors, such as worker behaviour and conduct, the used type of technology, site working conditions, and the design. In view of these facts, the site's safety management system should recognize the importance of safety hazards identification and contingent accidents precautions (Hadikusumo and Rowlinson, 2002).

In a regulated business environment with stringent regulations, it is important to support its processes by a versatile health and safety management software system providing the tools for logging and managing incidents, scheduling activities and managing actions. Technologies emerging from the advent of computers and software systems apply digital image processing resulting in the computerization of advanced infrastructure inspection methods. Digital image processing methods are now employed in many engineering and non-engineering applications (Lee et al., 2006).

Digital image processing is defined as the processing of Images and Videos resulting in restoring, enhancing, filtering, reconstructing, modifying, compressing, and extracting useful information from a video or a picture by the application of signal processing algorithms. Several image processing techniques have been used in multimedia classification and retrieval of images through the process extracting the contents of a picture or video and expressing it in mathematical terms thus providing a numerical representation of the item for the objective of similarity comparison. Furthermore, it can be used for video and image acquisition, segmentation, rendering, compression, storage, assessment, and retrieval purposes (Forsyth and Ponce, 2002).

The input data for the research work undertaken in this project is a set of digital site photographs of an existing building in Heriot-Watt University Edinburgh Campus. In order to use this available data for the purposes of the project these images needed to be processed and analysed. An important information in the representation of an object is the spatial distribution of the structural features of an object. A critical issue in the field of computer vision is the object's recognition methods which should be capable of identifying the partial occlusion of objects (Zaytoon, 2007).

This thesis major objective aims at analysing the onsite work conduct of construction personnel in various activities which is captured by the digital images obtained from site monitoring cameras. The analysis is conducted in relation to the encountered hazards and the suitability and effectiveness of the applied safety measures. The activities can be related to activity tracking, position tracking, and resources tracking. The objective is to reflect the awareness of the current project status in the decisions made by the project management at the construction sites. Automated tracking of important construction resources provides a timely feedback of the construction progress obtained by the analysis of information provided by installed sensors. The sensor technology applied can be Radio Frequency ID, Global Positioning Systems, or any other relevant technology such as that of visual surveillance (Health and Safety Executive, 2006)

## 1.2 Rationale for Study

The construction industry is making use of the new information technology advances by gradually replacing site cameras and their generated filing cabinets by digital ones with an electronic database. 3D image retrieval was a subject of research regarding the hazards facing workers in steel construction sites. Ahmed and Abid (2013) developed a prototype for implementing safety on construction sites.

Extensive work was undertaken to design a suitable safety prototype. For this purpose, questionnaires including relevant items from previous studies were adopted and modified through the conduction of pilot surveys and collecting construction project's relevant data. The questionnaire and interviews were done by contractors and other industry related professional representatives to obtain insight regarding the safety management practices in the construction industry. The results of these activities highlighted the requirement for appointing competent well-trained staff for proper implementation of safety on construction sites. This research project addresses this problem by developing a site safety training tool which can be used by site labour just before undertaken a scheduled work activity and thus reflecting the possible accompanying safety hazards and their associated mitigating actions.

Al-Shehri et al. (2013) highlighted the need for safety management to shift from the monitoring and management of accidents to monitoring and management of incidents. Attention to incidents will help to improve the understanding of the causation of incident in construction. Managing incidents takes place before the incident occurrence and is based on analysis of the causes of the incident in order to reduce accident events and improves safety, while monitoring incidents is after the occurrence of incident constituting a part of the control aimed at improving safety. The work undertaken in this project developed a system for analysis and the documentation in report form which can be used to identify the individuals involved in the violation of safety regulations in order not to repeat it

Al-Shehri et al. (2013) proposed a conceptual model for implementing such an investigation aiming at the development of suitable tools which are based on investigations results and serve to improve construction performance and safety.

Li and Xiang (2011) aimed at determining the main causes for poor construction safety from the viewpoints of workers, construction managers, government, and other related parties. The following conclusions were drawn:

1. There are four issues affecting safety on construction sites:

    - Object
    - Worker
    - Management
    - Environment

2. All related parties agreed that lack of proper management is a critical cause of poor site safety records; however different parties disagreed on the priorities of the other elements. While clients and managers identified the low quality of workers as an important cause, the workers themselves did not seem to realize the problem or appreciate it. In the same trend, managers did not give importance to the objective issue. In this respect, the quality of workers was signaled as a cause for poor site safety a gap which the present project tried to fill by focusing on workers site visual training.

Arayici et al. (2012) showed that the construction industry is being forced to increase efficiency, productivity, quality, sustainability, and infrastructure value in order to reduce lifecycle costs, lead times, and duplications. This trend is becoming more critical with remote construction projects due to communication and management challenges related to the remote locations of construction sites. Building Informational Modeling (BIM) is seen to be the solution to construction projects' interdisciplinary inefficiencies. It has provided several potential benefits and raised interesting challenges regarding the integration of the business processes of individual practices.

Arayici et al. (2012) demonstrated how BIM adoption in an architectural group helps to ease the communication and management problems in remote construction project by adopting a case study methodology. BIM was used between the architectural group and the main contractor for a remote construction project and it was showed that the key communication and management problems, such as unavailability of materials, poor quality of construction works, and ineffective planning and scheduling can be mitigated by the application of BIM at the design stage.

Lytle et al. (2003) reported on a workshop on automated steel construction the object of which was to investigate the impact of new technologies on the automation of the steel construction process. The workshop responded favorably to the idea of introducing new technologies to steel construction and confirmed the need for automation in this industry.

Yeung et al. (2014) investigated the possibility of automating the processes of:

1-identification of cross section

2-bolted connections end geometry

3-multi-component structural systems relative component position such as trusses.

The results of the proposed methods using filters and algorithms show a strong potential for full automated processes capable of identifying structural steel components and systems.

Although developing a knowledge management system such as BIM is not an objective of this research project, it was becoming apparent as the project was progressing that the model being developed can be used as a platform to incorporate such a management system. In this respect, the identification of site work stages and activities for the purpose of safety training can also be used for other management activities such as scheduling and cost and material control.

Further to multiple site visits to various construction sits in the UAE, reviewing the available literatures, and investigating the existing systems to clearly define the end user needs, it was concluded that the construction area still depends on manual approaches and lacks automation. The aim of this research is to develop prototype software integrating image processing using MATLAB, BIM using Navisworks, and knowledge management documentation tool to automatically generate health and safety documents and training material that can be viewed using advanced visualization tool, this prototype is an original piece of coding. Suitable software languages were used for each part with an extensive effort to ensure their compatibility, this prototype adds value compared to present methods used in existing sites.

## 1.3 Aim and Objectives

Steel structures construction is recognized as one of the jobs prone to hazard in the construction industry. Several factors contribute to the safety in construction. These factors are related to the workers' training standards, the technologies being implemented, the working conditions at the construction site, and the project's design. Even with the close implementation application of international hazard prevention and safety codes and standards the fatalities and injuries in the steel construction site are very high compared to other work sites demonstrating the need to improve both the relevant procedures and their implementation.

The aim of this study is to develop a system model for steel structure construction including a software package based on the image analysis and recognition of a set of site construction digital photographs for the purpose of detecting safety hazards and outputting labour training material mitigating these hazards together with the automatic output of relevant site safety reports. The output will also serve as an input for knowledge management decision making tools and hazard prevention tools for future projects.

The objectives sought from the developed computerized model are:

1. Identify activities of a high-risk profile within the construction industry e.g. steel construction and review previous research and literature addressing the safety issues in order to introduce automation to this field.
2. Determine the extent of computer visualization tools that can be used in construction sites supporting safety issues and whether they are adequate for progress monitoring.
3. Develop a computer software package capable of recognition and analysis of digital images.

4. Develop a system for identification of specific activities within steel construction and defining the safety hazards associated with these activities.
5. Automatic output of safety training material related to the identified activities, and output of site safety reports.
6. Knowledge Management tool to support decision making and accident investigation.

### 1.4 Structure of the Thesis

This thesis is organized into nine chapters and five appendices. A brief summary of the various chapters is provided below.

*Chapter One* is an introduction to the research, it presents background information on health and safety in construction, rational of the study, describes the aim and objectives of the study and its limitations.

*Chapter Two* this chapter contains an overview of health and safety in construction in general and in steel structure construction especially in addition to the usage of building information model in construction, computerizations, image processing and recognition in health and safety in construction.

*Chapter Three* is intended to highlight the role of health and safety in construction in general and in steel structure construction in particular. It describes the hazards faced in each stage and their possible associated accidents. The accidents' preventive actions through the use of videos and animations are described together with the proactive approach of accidents' prevention by design. The role of automation and its impact on safety is briefly reviewed due to its possible linking to the anticipated daily site task through the task identification part of the developed computer model. It is understood that this is not being undertaken during this project but can be a future subject building on what has been generated.

*Chapter Four* reviews the various research philosophies, methodologies, and strategies in order to identify the grounds for selecting the one approach suitable to the work intended for this project. The chapter goes along to describe the stages undertaken in implementing the selected approach which includes the conceptual model development, survey objectives and data collection, choosing a suitable data sampling method, the development of the computer model, and the validation of the obtained results.

*Chapter Five* this chapter is dedicated to the questionnaire survey being conducted. It discusses briefly the surveying methods with special emphasis on the questionnaires method and outlines the objectives sought from the survey. The invited participants and their responses are shown as results and are analysed in order to draw the relevant conclusions from this exercise.

*Chapter Six* this chapter is about the development of the visual software model whose aim is the enhancement of safety in the steel construction industry. It touches briefly on the theoretical background related to the software model's subjects including knowledge management in general and in the construction industry in particular, information technology, the Building Information Model (BIM), and the simulation approach in education and training together with its application in project progress monitoring.

The main body of this chapter is intended to describe the developed Model (Construction Automata) and its system's specifications. It describes the system architecture, design, and functional requirements for users, user cases, diagrams, and use cases. The business rules and class diagrams related to the input data together with the output forms are also presented.

*Chapter Seven* this chapter explains the framework and operation of Construction Automata. The chapter starts with a brief description to the steel construction site activities in order to selects suitable specific ones to be monitored by the developed software package. The chapter then describes Construction Automata modules and user cases providing a step by step approach in explaining the displayed computer screens which appear during operating the software model.

*Chapter Eight* Research Verification and Validation processes were reviewed and the scoring model validation approach was selected and applied using the results obtained from a case study demonstration of Construction Automata to a selected group of experts. The results obtained from the developed computer model were subjected to relevant verification and validation exercises to demonstrate the model's relevance and usefulness. The chapter also reflects the strengths and weaknesses of the model and future work that can be carried to improve it.

*Chapter Nine* draws the relevant conclusions based on the results obtained from the computer model. The chapter also identifies areas for future research work to pursue and investigate in order to expand the scope of use of the model.

# Chapter 2– Literature Review

## 2.1 Introduction

This chapter seeks to survey the available literature related to the relevant main topics of this research project. The sought target of the project is to reduce accidents rates and injuries by improving the health and safety awareness and training in the construction industry using an automated approach. Hence the literature survey focused on topics related to construction health and safety in general and those concerned with steel structure construction in particular.

Since the initial data available for this project is in the form of a set of construction progress monitoring photographs for a steel structure building, image processing and recognition became a pivotal subject to be investigated. Also, and in order to build a real-time model suitable for knowledge management and safety training, the literature related to computerization in construction and the 3D and 4D applications were surveyed.

The real-time 4D modelling pursued in this project provided the foundation for information modelling systems applications such as the Building Information Model (BIM). Although its implementation in this project was limited, however, due to its rising importance in construction project management and the possibility of it being a future subject of research based on this project, the available literature related to it was also reviewed.

## 2.2 Health and Safety in Construction

The word “Safety” accompanied with “Health” is so commonly used that it should be simple to define it, Lampl (2005). However, dictionaries do not offer much assistance. Safety is defined as: “The absence of danger or a state of protection and a condition not involving risk”. However, it is not possible to achieve absolute safety because there is a risk at all times, however small it may be, of things going wrong. Similarly, ‘health’ is also a relative notion, in the sense that people will always be those in varying states of wellness. Thus, the expression of “Health and safety or H&S” is used every day in the workplace to convey the idea that workers leave their work as 'healthy' as when they arrived. The joint management at the work place of “health and safety” rendered that the word 'safety' stands for both.

Alli, (2008) concentrated mainly on the health and safety at the Construction area by presenting the major threats that appear in the construction workplace and the systems to be implemented in order to enhance H&S in work sites. In addition, the two topics of effective communication between the stakeholders in the group and the changes of culture at the site in order to make it H&S positive were discussed. This work highlights the areas of risk in a construction site and the general required mitigating actions. It draws the attention to two important topics which form the basis for the work represented in this thesis namely the need to consider the workers cultural background impact on safety and selecting the suitable method of communicating the safety training based on this background.

The subject of site health and safety needed to be related to specific site activities in order to select a suitable one for this project. The general definition of occupational safety and health (OSH) is “the science of recognition, anticipation, control, and evaluation of hazards which arise from work related activities or that takes place in the workplace that impairs the well-being and health of workers, taking into consideration the possible impact on the general environment and surrounding communities”. This is a broad definition covering several disciplines, a verity of sites, and numerous hazards. An extensive verity of structures, knowledge, skills, and analytical capacities are required in order to come up with national OSH systems, which protect workers and the environment (Alli, 2008**)**.

Lehtola et al.. (2008) states the importance of health and safety from an occupational point of view, which reflects on the company’s success and sustainability. However, for many people, OSH is limited to covering the immediate accidents caused safety issues rather than the less immediate issue of occupational health.

Alli (2008) defines industrial safety as the discipline concerned with safety engineering and public health which controls the work environment in order to protect the worker’s health from accidents and unsafe working conditions leading to injuries which reduce efficiency and results in loss of productivity.

The work undertaken in this project is related to the subject of accidents prevention by developing a training tool limiting work related accidents.

The concept of site risk and its management needed to be identified in general in order to provide the foundation for selected work hazard and its management. Pipitsupaphol and Watanabe (2000) defined “Risk” being the probability or chance that a person will be harmed or experience an adverse health effect if exposed to a hazard. In this context risk management depends on four related elements:

(1) The identification of hazards.

(2) The analysis of risk.

(3) The selection of risk control.

(4) The maintenance and implementation of risk control.

The management of OSH risk has been focused on construction sites. A valid current argument is that preconstruction planners and designers are in a good position to reduce or eliminate risk before the work starts at site. Construction hazards are classified into four categories, which are: (Finneran and Gibb, 2013**)**

- Nature and physical layout of job site conditions.
- Materials and equipment.
- Human factors.
- Management factors.

Construction industry is selected in this project, based on the fact that construction industry includes operations that can put the workers in its domain in risky and unhealthy circumstances with high chances of injuries, accidents, and illnesses exceeding those of other industries e.g. the manufacturing industry.

Kadefors (1995) and Dubois and Gadde (2002) reflect this fact and conclude that it is due to the construction industry is composed of a transient workforce from different cultures and backgrounds with different attitudes and behaviours towards safety working together in a changing organization and structure.

This fact leads to continued delays and related costs overruns in construction projects. Proper site management protocols and procedures need to be implemented in order to render a working site “safe” for operations. A construction site includes both permanent works and temporary ones which are related to the construction phase only both of which have their related risks. Elbeltagi and Hegazy (2002**)** outlined the related influencing factors regarding safety issues on construction sites in regards to temporary facilities arriving at a quantitative approach that will improve productivity and safety. These factors are:

- Data base identifying facilities and their size.
- Quantifier to address facilities locations.
- Search algorithm for an optimal layout.

The design phase hazards management is not part of this project however design safety considerations embedded in 3D digital design packages can be used to reflect the required safe work execution when designing the safety training models.

Elbeltagi et al. (2004) defined three aspects during the planning phase which results in site safety improvements:

(1) Temporary safety facilities required at construction sites;

(2) Safety zones around the construction space;

(3) Safety considerations when determining the optimum facilities' locations within the site.

Gambatese et al. (2005) presented a pilot study to determine the feasibility of construction worker's safety consideration during the design phase of a project and its possible reflections on the project cost, and project schedule. The results of the pilot study indicated that incorporating safety considerations during the design phase is a viable intervention. They also described the changes that need to be put in place for the implementation of this concept.

Toole et al. (2006**)** reviewed the design for construction safety (DfCS) concept and presented practical and specific ways for its incorporation together with the barriers facing it. The identified fields are increasing:

- Prefabrication
- Use of less hazardous systems
- Consideration of safety issues during construction engineering
- Awareness regarding the utility systems surrounding the construction site.

Toole, Hervol and Hallowell (2006**)** presented practical and specific steps in which structural engineers and steel detailers can implement the design for construction safety concept (DfCS) and identified possible barriers facing this initiative.

Misnan and Mohammed (2007) established a framework for introducing the safety culture in the construction industry thus providing a safe environment in a dangerous industry.

The reviewed literature addressing the subject of safe design reflects its importance in the reduction of construction hazards related to its execution.

The site construction activity includes operating equipment and machinery. The Safe operation of equipment is another safety concern on construction sites.

Chi et al. (2008) presented a preliminary control system framework for crash avoidance of heavy equipment which includes algorithms facilitating active safety for equipment operation.

Lingard and Rowlinson (2005) highlighted the importance of the human element importance and the role of omissions and errors in occupational accidents and system failures of a catastrophic nature. Lack of appropriate safety protocols and poor training are also considered to be important in causing construction accidents. This work brings the attention to the importance of training which is the method sought in this project for improving site safety.

The cultural aspect needed investigation to determine its relation to construction safety. Finneran and Gibb (2013) show that OSH practice and performance differs around the world with some leading regions making progress over the years to emphasize on behaviour health and safety while lagging regions are still concerned with acute effect injury risks. The time needed to move from one region to the other is measured in decades.

The cultural element was a factor in selecting visual training in this project to cater for labour with different languages or language skills.

Further characteristics that define the construction industry and have an impact on its safety issues are that its companies are operating internationally in projects of different size and nature. Choudhry and Fang (2006) showed the challenging situation in a construction environment due to the fact that projects differ in terms of size, location and complexity.

Cox and Cox (1991) reflect the difficulties associated with the fact that OSH management requires sustained and co-ordinate efforts. This is due to the construction being a worldwide transient industry and construction companies are not centralized which results in that common beliefs, attitudes, and culture, are not easily developed among the project's parties.

Lingard and Rowlinson (2005) show that the innovative phase integrates OSH into the business making decisions, and technological solutions are used to eliminate hazards or minimize OSH risks. Cultural and motivational subjects are taken into consideration in this stage, and work is structured to support good OSH performance**.**

The safety culture in a construction company as an example and in the construction industry in general is an accumulative process. Pybus (1996) developed a model to illustrate the evolution of safety culture over time. There is a correlation between the improvements of the safety culture of a construction company with the reduction in illness and ill-health. At each phase start a reduction in accidents or ill-health incidents is achieved which is the followed by a plateau of performance before moving into the next phase.

The literature reviewed highlighted the need for a proactive approach to construction site safety. Finneran and Gibb (2013) state that the traditional approach to Occupational safety and Health (OSH) is essentially reactive, where hazards are handled when they strike. Emphasis should be given to a proactive approach whereby hazards are considered before arise and disciplines such as the use of personal protective clothing and equipment should be enforced.

The industry needs to move to the inventive stage of OSH management in order to achieve further improvement, however the complexities of the industry makes this target rather difficult. It is also important to significantly progress the previous phases in order to ensure that a concentration on culture in the third phase can be effective. This requirement was recognized and adopted in this project by providing site training prior to conducting a construction task.

In order to build a safety model for site construction activities certain specific facts needed to be established. Kotze et al. (2008) list five main practical steps whose implementation will help improve H&S in the workplace:

Steps 1 – Identify the likely hazards in cooperation with workers and members of staff.

Step 2 - Decide who might be effected by the hazard and how.

Step3 - Evaluate the risk associated with the hazard and decide on the required precautions.

Step 4 - Record the steps taken and their implementation.

Step 5–Update the assessment when needed.

The need to verify that training is a decisive factor in reducing construction site hazards and improving safety was required to justify adopting this approach in the work undertaken in this project.

Kotze et al. (2008) discussed the effective communication in the construction area and state that effective communication should start from the standardization of the documents. The standardization process leads to simpler dealing with documents, trainings, communication planning, etc.

Myers (2003) and Wilson and Koehn (2000) claim that recognizing H&S as an important performance indicator shall lead to the improvement of safety in the construction industry.

The factors leading to accidents at construction site were approached by several researchers. Toole (2002) identified the causes of construction site accidents as being the deficiency in relevant training, safety enforcement, and safety equipment's. Other causes are the unsafe methods, unsafe site conditions, poor safety attitude, and sudden deviation from prescribed behaviour.

Dester and Blockley (1995) and Sawacha et al. (1999) show that unsafe behaviour is a significant factor in serious construction site accidents such as fatalities caused by falls, struck-by incidents, and electrocutions.

The financial impact of injuries among the working force need to be investigated in order to establish the incentive for construction companies to improve their safety records. Construction accidents lead to economic losses. Everett and Frank (1996) estimate these losses to be 7.9% to 15% of the total costs of industrial new construction. Furthermore, Coble and Hinze (2000) puts the average insurance compensation costs of workers at3.5% of the total cost of the project. Kartam (1997) stresses the impact on the reputation and productivity of the industry beside the obvious economic losses.

Hinze et al. (2006) examined the effects of slight injuries in terms of number of affected workers and the average cost of these injuries. 136,000 construction worker minor injuries were studied and it was found that over half of the injuries were sustained by the upper extremities, lumbar spine or eyes.

Recently several software applications were developed to facilitate H&S management in the construction industry based on safety database systems. The existing applications were reviewed in order to identify an area of importance that was not addressed properly.

On the subject of onsite safety improvement, the study of Oloufa et al. (2003) developed and implemented systems for tracking of vehicles and collision detection utilizing Global Positioning System (GPS), and web-based wireless technologies.

Other safety systems were developed dealing with the training activity in Health and Safety. Huang and Hinze (2003) and Aksorn and Hadikusumo (2008) relates the improvement of safety performance to the safety training. Hislop (1991) and Tam et al. (2004) claim that the best improvement of site safety performance can be achieved by the training of construction workers.

Zeng et al. (2008) pointed in his study that implementing relevant training programs to employees could prevent accidents such as being hit by falling materials or falling from heights.

Similarly, Dingsdag et al. (2008) show that construction workers singled training as being the important element in safety performance.

Tarrants (1980) and Sawacha et al. (1999) identified the relation between individual safety behaviour and safety performance.

Training can reduce unsafe behaviour significantly. Fang et al. (2006) stated that the safety climate of workers with good safety knowledge is better than that of workers with lesser safety knowledge.

Langford et al. (2000) identified training together with the knowledge and competence of operatives and safety supervisors as critical factors influencing personal safety performance.

Langford et al. (2000**)** also stated that maintaining and updating workers' knowledge and skills by training, updating, and site communication should be pursued by companies and contractors.

Findley et al. (2004) show that successful training can minimizing construction accidents and project delays resulting in damaging the company's image**.**

Gervais (2003) proved that construction accidents are caused by the lack of safety training of construction workers.

Elbeltagi and Hegazy (2002) presented a quantitative approach to maintain a safe and a productive construction sites. The factors that contribute to unsafe sites were outlined whose consideration during planning will result in a safe site and the increasing of productivity.

Gambatese et al. (2005) presented a pilot study to evaluate addressing the worker's safety during the project's design phase to determine its feasibility and practicality bearing in mind the project's cost, schedule, and design creativity.

The results of this study confirmed the viability of the approach and identified the requirements and changes to the design procedures and designer's mindset which need to be introduced.

All of the work related to existing safety applications recognized the importance of training. The missing application was that adopting a site visual proactive approach. Such an approach addresses the cultural issues and is effective due to the fact that it can be tailored to the daily work task thus being relevant and fresh in the memories of labour.

## 2.3 Health and Safety in Steel Structure Construction

The construction industry includes many work activities which are different in nature. For the sake of practicality one activity needed to be selected and focused upon. Steel construction is a major activity in site related works and has the unique characteristics of being largely fabricated off-site. On-site erection and assembly are done rapidly hence the coordination of all parties is important in achieving the potential schedule advantages.

Mrozowski et al. (1999) state that steel components constitute a major part of a construction site inventory. Its versatility allowed the construction of simple and complex structures in an efficient, time saving, and economic manner.

The literature reviewed identified steel construction as a high source of risks and hazards which lead to its selection to be used in the safety model developed in this project.

Sharqi et al. (2012) state that steel structures' construction remains the construction industry job most prone to hazards. Construction safety is a combination of many factors such as worker's training standard, site working conditions, the implemented construction technology, and the design of the project. This fact illustrates the need for improvement in the safety implementations and procedures in steel construction sites. Even with the most stringent implementation of international hazard prevention and safety standards and codes, the deaths resulting from falls in the steel construction site activity as an example is double that compared to other works on construction sites.

This fact illustrates the requirement for safety implementations and procedures improvement in steel construction sites. Accordingly, precautions and hazards identification are important components of any safety management system at construction sites. The success of a project is measured by the safety in its construction. In developed countries, safety is always the main concern and is closely controlled whereas in some developing countries it is given a lesser importance in order to reduce expenses, and thus results in many accidents that seriously affect the project.

Pope (2004) show that most aspects of unsafe practice become apparent at the erection stage whereby design decisions and restrictions from other contractors reflect on the ability of the contractor to perform safely.

Kakakhel et al. (1999) define and list the responsibilities of the general contractor of a construction project. Although the general contractor frequently subcontracts to subcontractors, the responsibility for the means and methods and their associated safety practices for various building components; the general contractor still retains certain fundamental safety responsibilities. The authors also list the points requiring special attention to protect steel workers in the various phases of the project.

The drawn conclusion is that the erection phase in steel construction is the most hazardous one and that training should be addressed to the main contractor whose responsibility covers the whole construction site.

## 2.4 Building Information Model (BIM) in construction

The site construction control activities include materials, time scheduling and cost. The most effective control is an interactive one in the form of a knowledge management system. The literature review was concentrated on investigating the building information modelling (BIM) being a system gaining significant recognition in the construction industry.

Building Smart (2012) and Isikdag and Underwood (2010) draw the attention to the fact that Although BIM has been known for quite some time, it has just began gaining recognition and awareness.

Bratton (2009) points out that there is no universal agreed definition to what “Building Information Modelling” means regardless of the several proposed definitions. However, there is some agreement on the general themes defining the concept of BIM which includes 3D modelling, information database technology, and interoperable software which is used for the design and simulation of various construction activities.

While Bazjanac (2006) describes a building information model as a system which characterizes the spatial relationships, geographic and geometry information, properties and quantities of building elements, project schedule, material inventories, and cost estimates.

Azhar et al. (2008) analysed three questionnaire surveys in order to identify the role of BIM in the construction industry.

Survey 1 by Kunz and Giligan (2007) aimed to determine the added value from using BIM and the factors contributing to its success. The main findings of their study were that BIM can be used across the board in all disciplines and activities, it provides efficient clash detection, and leads to increased productivity.

Survey 2 by Khemlani (2006) was conducted to identify the most important requirements for BIM to satisfy. The identified requirements were the production of complete sets of project's documents, enabling simultaneous working multiple teams' members, supporting tutorials, supporting design modelling, and integrating applications.

Survey 3 by Dean (2007) was carried to determine whether BIM should be taught to students in construction management. The study established this need based on facts that there is increasing trend of BIM use in the industry, and the employment advantage which BIM trained candidates enjoy.

In another study, Woo (2006) recommended to integrate BIM in existing construction courses to provide the required knowledge for an AEC industry candidate.

Azhar et al. (2008) states that the building Information modelling (BIM) represents new developments in the engineering, architecture, and construction (AEC) industry and is becoming a familiar expression. The Building Information Model created by this technology can be used in the planning, design, and construction phases of a project.

Bratton (2009) defines BIM as being an integrated process which outputs a graphical representation of the functional and physical characteristics of a building using continuous information received at different stages of the building lifecycle. This definition illustrates that BIM can create a collaborative working platform for the Integrated Project Delivery (IPD) process. BIM treats the total process as a whole by inviting the contribution of key decision makers and capitalizing on their experience and perspective. This is not like the traditional linear progression method where construction process disciplines wait for each other completion.

Singh et al. (2011) and Autodesk (2011) stipulates that IPD creates a streamline transition between the project's stages resulting in the minimization of lost information and delivering detailed information to clients beyond what was done previously.

The role of BIM as a materials control tool was shown by Khemlani et al. (2006**)** that BIM can extract quantities and shared properties of materials and defines scopes of work. Systems, sequences, and assemblies can be shown in a relative scale with the group of facilities or the entire facility and the construction documents can be easily interrelated

Another important feature of BIM is its ability to provide a comprehensive visual concept of the project which can be used as a demonstration model on one side and clash detection on the other side. On the modelling side the, CRC Construction Innovation (2007) describe the key advantage of BIM as being the precise geometrical representation in an integrated data environment of all the building's parts.

Wang (2011) states that 3D building modelling has become ever more used as a competent method that improves the way the construction industry projects are being delivered. It is used as a design tool by architects to provide their clients with a 3D vision of their design ideas. Engineers also are benefiting from the use of BIM and 3D to obtain a better coordination for their designs and to incorporate their analytical services by detecting systems' clashes and energy efficiencies estimations.
Azhar (2011) points out that the focus on the preconstruction phase has dominated most of the discussions associated with BIM. However, and until now not much notice has been given to the recently emerging topic of the site linked model.

Sullivan (2007) focuses on the benefits and meaning of using the BIM concept to describe site conditions which identify collisions to decrease errors and field corrections, having better dependable anticipation of field conditions enabling a safe environment, and incorporating more prefabricated components.

An example of the use of BIM in modelling and collisions detection was presented by Ospina-Alvarado and Gerhart (2008) that looked at some relevant examples like the design and construction of Emory Psychology Building, located in Atlanta. The BIM proved to be very competent in defining underground coordination. In this example, a site model was created, the early collision interference and detection checking was done, and a utility model was created using a 2D drawing which presents the structure in relation to the underground utilities and thus revealing all conflicts.

Gerber et al. (2010) view the Building Information Modelling (BIM) as an emerging approach that will help the construction industry eliminating waste, improving team productivity, and cutting costs. BIM is also seen as an integrated, collaborative process involving all disciplines through the building lifecycle.

BIM required a cooperation between researchers in the field of construction knowledge management and software developers Wong and Yang (2010) indicate that the cooperation between researchers, software developers and industry practitioners led to the establishment of (BIM) as an important emerging technology and procedure introduction to the Architect Engineering and Construction industry. BIM assisted this industry in developing new ways of thinking resulting in a significant impact on its professions.

Azhar et al. (2008) list the uses of the BIM as 3D visualization, forensic analysis, production of fabrication drawings, automatic cost estimation, material ordering, and collision detection.

The software incorporating the relation between the 3D design model and real-time construction activities initiated the idea that such software developed for another purpose e.g. site safety, can be used as a platform for incorporating BIM related activities.

## 2.5 Computerization in Construction

Although the construction industry is an old established industry however the reviewed literature indicated that most of its activities are manual and computerization is being recently introduced. This gave the assurance to the need of automated safety training and reporting systems.

Hartmann (2008) shows that Owner, Contractor, and Society are the main components of any project and there is a considerable amount of communication, information, and work between them. Technologies play a principal role in facilitating the project for all parties.

Projects construction requires the latest technologies in order to increase the productivity, enhance the performance of workers, and improve safety which can only be achieved by automation and computerization.

### *2.5.1 Impact of Technology on Construction regarding 3D and 4D model applications*

The professionals in the construction industry acknowledge the potential of the 3D and 4D technologies. Verma et al. (2010) point out that researchers' evaluations define 3D and 4D models as leading useful technologies in construction within industrial or educational settings. Moreover, these technologies play a significant role in the administration of project construction.

However, one field which is not making the best of these technologies is that of construction safety. There are not many case studies that demonstrate these technologies in this field, however their understanding is considered to be the starting point to understand the effective utilization of 3/4 D model technologies.

The following descriptions are applications examples of 3D/4D model in project construction in general.

i. Photorealistic Rendering

Verma et al. (2010) states that it is possible to use 3D/4D model technology for marketing purposes by the developer, builder, and designer of projects. It can also be used to involve the community in public projects by presenting clear pictures to their customers of the finished project by using 3D short movie clips**.**

ii. Virtual Design Review

Hartmann et al. (2008) show that the 3D technology can better demonstrate complex geometries which cannot be demonstrated effectively by 2 D technologies. Moreover, it improves the quality of dialog between the project team and the owner by helping designers to convey their design ideas clearly. Another important benefit is its ability to better detect clashes and interferences early in the process.

iii. Analyzing Construction Operations

Hartmann et al. (2008) demonstrate that 4D and 3D can be used for progress monitoring of the work at any specific time by project managers. This technology defines the schedule and sequence of construction and increases the accuracy of construction operation by reducing the conflicts and errors which will result in enhancing the strategies related to the administration of project construction.

iv. Construction Document Production

Hartmann et al. (2008) demonstrate that 3D/4D plays a role in organizing the construction and design documents. As a result, a library of standard reference specifications, settings, and parameters is established by this technology which could be linked to the procurement activity thus reducing materials orders' lead time.

v. Bid Package Preparation

Hartmann et al. (2008) concentrate on the client/contractor relationship where by the owner requires definite picture of the performed scope of work conducted by the contractor and the subcontractor. The contractor and the subcontractor are both being helped by this technology to prepare to the owner a very clear bid-packages reflecting their plans.

### *2.5.2 Impact of Technology on Construction regarding Computer Programs application*

Software has been developed to manage such works as cost estimating, accounting and scheduling. In Some projects, LAN is installed in site offices for the purpose of sharing resources such as files, drawings, and printers. The necessity for the establishment of computer application strategies is now recognized in order to computerize the building industry.

Kassab et al. (2010) demonstrate that Computer programs have an important role to play in the administration of project construction and give the example of such programs as that of computerized DSS (Decision Support System) which is used for the resolution of construction conflict under uncertainty. The VBA Microsoft Excel programming language is applied to develop DSS. This program is designed to provide balanced solutions to all parties in the project. It depends mainly on the input information helping its users to decide on the course of action or negotiation strategy toward a dispute as shown in below figures (2.1).

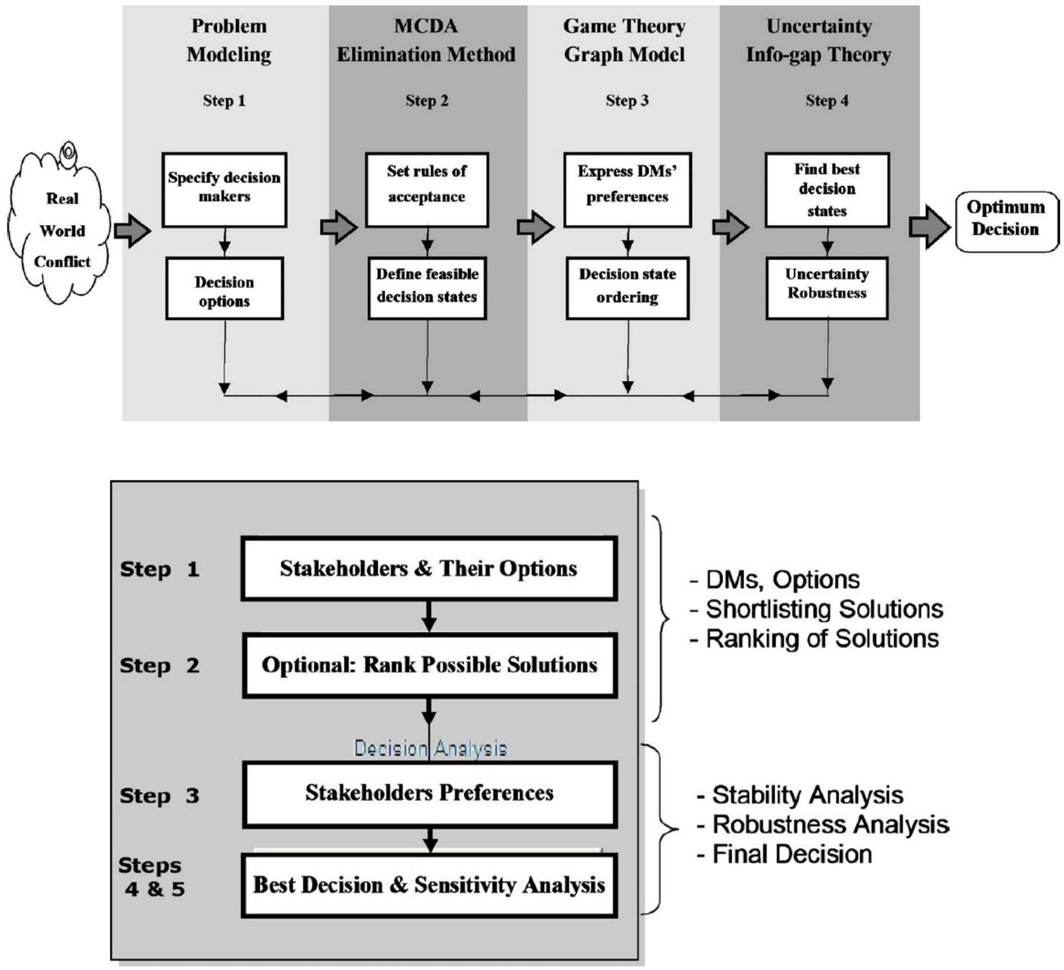



Figure (2.1): DCC Flow Diagram. Kassab et al. (2010)

Ma and Chen (1998) claim that the use of computers in construction management in recent years has been expanding rapidly due to the improvement of their cost to the ratio of performance.

Ma (1997) indicates that Computer Integrated Construction (CIC) alongside the Computer Continuous Acquisition and Lifecycle Support (CALS), are being promoted in the field of Computer Aided Engineering for Architecture/ Engineering/Construction (AEC). Both CIC and CALS shall have a significant impact on the computerization of the building industry**.**

Brown et al. (1998), Froese (1996), Stumpf et al. (1996), and Rezqui et al. (1998) state that many models have been created together verification systems in order to facilitate the application of CIC and CALS.

Zhiliang and Juan (1999) highlight the rising trend in the use of CALS and CIC in AEC. However, many problems remain unsolved such as the application of general models developed for specific domains in developing commercial applications.

This review highlights the increasing introduction and role of computer program applications in the construction industry. However, the lack of specific applications related to safety issues was evident and confirmed the validity of the work envisaged in this project.

### *2.5.3 Traditional pattern of information management*

Zhiliang and Juan (1999) indicate that traditionally, the project's team has to do repeated works causing inconsistency and redundancy hence invalidating some of the project's data. Although computerization was introduced in some processes such as scheduling, its use was not comprehensive and the result needs to be copied in paper form to be used by other staffs. This fact highlighted the importance and efficiency of adopting a collaborative environment.

### *2.5.4 New pattern of information management*

The new work environment is a common place containing the work tools required by each staff where he can exchange data with other staffs conveniently and immediately. This collaborative environment needs a unified and a central data platform.
Zhiliang and Juan (1999) define collaborative working in general as each staff can concentrate on his work and the results can be shared immediately by other staffs while the work is still in progress.

The concept of breakdown of the project needs to be introduced as the construction stage includes many phases. Furthermore, each phase includes several processes e.g. the construction of the main structures construction includes formwork installation, binding of steel bars, inspection hidden work inspection, and the in-site casting of concrete. Also, each process consists of several actions such as the filling of data forms. A building for example is divided into construction parts in each floor, so that the above activities and processes have to be repeated for each part in each floor**.** System configuration becomes essential in managing these phases, processes, and parts.

Zhiliang and Juan (1999) claim that construction project information management is based on system configuration. A LAN in the office of the construction site is constructed with the software of the joint environment respectively mounted in the server and in the client. The server is used to run the database management system and store the full management information of the project as a combined central data platform. The client can then run the applications for the relevant staff.

This new pattern of information management implies the development of suitable interactive software applications which formed the basis for determining the interactive nature of the knowledge management and safety model attempted in this project.

## 2.6 Image Processing and Recognition

The work undertaken in this project was based on extracting specific information from a set of digital photographs to be used in developing a construction safety application. The general subject of image processing and recognition as a science not specifically related to either the construction industry or safety shall be reviewed first as an introduction. The second subject related to the applications of image recognition techniques in the construction industry will follow. The third subject focuses on two sub sections regarding the safety aspects in construction sites in general and the utilization of image recognition in generating automated safety systems replacing the existing manual or semi-automatic methods currently being used.

### *2.6.1 Introduction*

Digital image processing is the process in which a digital computer is used to process digital images which is composed of a fixed number of elements (pixels), each having a particular value and location. Pixel is the most widely term used to describe the image elements, Gonzalez et al. (2009).

It can also be viewed as the use of computer algorithms to perform image processing on digital images. It has identical advantages to those which the digital signal processing has over the analogue signal processing by employing a wide range of algorithms to the input data thus avoiding during processing the usual problems such as the build-up of signal distortion and noise. Digital image editing is the most common kind of digital image processing (Rosenfeld, 1969).

Do (2007) utilized a database of image characteristics to develop an image recognition technique useful for the recognition of structure images and fixed shapes such as documents and paintings. He used33 different classic paintings' images taken by a camera phone to construct the database. A MATLAB code was then written for the purpose of image recognition. 80 % of the images which were taken were correctly recognized.

This demonstrated the suitability of the MATLAB code for image recognition and lead to its adoption in this project.

The need to use suitable filters was considered by Do (2007) who showed that characteristic points are detected by the use of low pass filters for the reduction of noise. Morphological operators such as majority filter and dilation and the Haralick corner detector are used for clear and smooth boundaries. Original images are thus trimmed to become smaller and containing only the region of interest in order to construct a database consisting of small size images. Then each image is sub-sampled to become a fixed size grey image 200 by 200 pixels. Sub-sampling can reduce angle/position of camera and any discrepancy of trimming position. Haralick corner detector is used to select 100 corner points per image which have large corniness. The points are then positioned on a 200 by 200 binary image, which becomes the reference image in the database.

Pattern recognition was studied by Chang and Lui (2001) who classifies patterns based on extracted statistical information or a priori knowledge of these patterns. This is in contrast to pattern matching whereby the pattern is rigidly specified. The classified patterns are sets of measurements or observations which describe points in an appropriate multidimensional space.

A two-dimensional function (x, y) is used to define an image, where x and y are plane coordinates, with the amplitude at any pair of these coordinates being the grey level or intensity of the image at that point., as shown in figure (2.2).

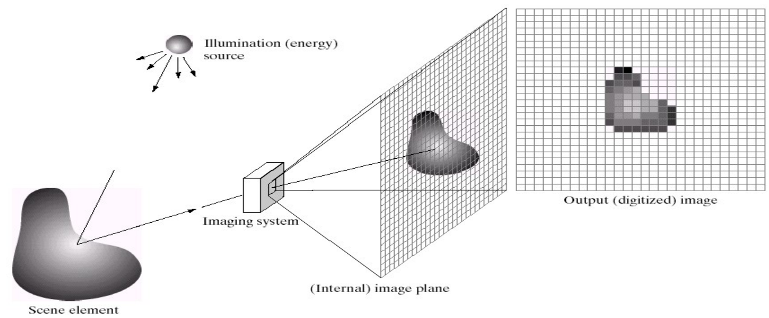



Figure (2.2): The Intensity of an Image Drawn from its Dimensional Coordinated (Gonzalez and Woods, 2006).

The 2D image processing is used for two different purposes:

a) Improvement of the visual appearance of the images to the viewer,
b) Measurement of the image structures and features.

There is a considerable overlap between the techniques used for each of the above purposes however they are not exactly the same.

An analogue Image is represented mathematically as a continuous range of values of intensity and position while a digital Image is restricted in its allowed intensities and spatial coordinates.

The term image processing refers to the following operations:

- The classification of the image.
- The acquisition of the image.
- The enhancement of the image.
- The restoration of the image.
- The color processing of the image.
- Wavelets
- The compression of the image.
- The morphological processing of the image.
- The segmentation of the image.
- The representation and description of the image.
- The object representation of the image

Knowing the uses of the processed images is helpful in selecting the optimum approach. Russ (1998) states that the visual enhancement requires knowledge of the human visual process and an understanding of the cues which the viewer responds to in images. Knowing the printing process is also useful since several images are processed in the form of transmission or reproduction. He also claims that images measurement requires that the image features are well defined by colour, edges, texture, unique (and uniform) brightness or a combination of these factors. The appropriate processing steps are determined by the types of measurements that will be executed on individual features or entire scenes. Image processing, like word processing, simply rearranges the data and does not reduce it.

Do (2007) developed a well-known image recognition technique useful for mobile camera phones or computer based automated recognition systems is the Eigen image method. This method is able of rearrange highly complex objects such as a human face. Furthermore, it can recognize and classify a large number of different groups by collecting information from a large group of training set images having identical characteristics.

### *2.6.2 Image Recognition in Construction*

The project progress current level in a specific construction activity e.g. “concrete columns” can be measured once the column installation activity is identified and counted. However, a vigorous object recognition methodology is needed in order to identify and count the installed number of concrete columns at a particular point of time. The successful extraction and recognition of the construction object of interest is key to the understanding of the current level of project progress. Han et al. (2010) indicates that the project status information can be automatically obtained from construction-site images provided by digital cameras

The construction object recognition primary application areas are quality assurance, reconstructing building models, and progress monitoring, Lukins and Trucco (2007).

Brilakis and Soibelman (2006), Choi et al. (2008), Kim et al. (2008), Memon et al. (2007), Zhang et al. (2009), and Zhu et al. (2010) all have explored the use of camera, stereo, and video sensors to evaluate construction operations present position and to inform human operators or automated planning QA/QC systems.

Navon (2007) provides a review of the call for the automation of progress monitoring being driven by the high requirements of labour for the collection of data, the low quality of the data being collected manually, the resulting irregular project control, and the deficiency of real-time input needed for corrective measures.

An important document in any building project is the as built drawings. Tang et al. (2010) surveyed methods for generating as-built building information models from 3D data. Extensive work was conducted regarding reconstructing buildings from airborne LIDAR data using construction object recognition from laser-based 3D imaging. Examples include the work of Maas and Vosselman (1999), Rottensteiner and Briese (2002), and You et al. (2003).

There is rather little work regarding explicit recognition of construction object from terrestrial laser-based 3D imaging systems

Gilsinn et al. (2005) examined 3D imaging recognition of construction objects by experiments aimed at recognizing a single steel beam located on a flat ground level surface which is being imaged in various rotations. A laser-based large-scale digitizing system was used to provide a ground truth. There used cognition approach was a bounding box match utilizing principal components analysis (PCA) on the divided points of interest. A 3D occupancy-grid approach was also used to simplify the observed data and reduce its elements. Voxels were tested and selected based upon a combination of adjacency and height above ground.

Comparison between known samples and image contents was investigated by Brilakis and Soibelman (2005) who presented a methodology for material identification using the concept of retrieving content based images in order to match material groups within the image content with known material samples. The results confirm the method’s suitability for the recovery of construction site images. Also, it demonstrates the capabilities of the existing image processing technologies in the accurate identification of many materials extracted from the images of the construction site.

The capability of automatic identification of objects, materials, and shapes, from the image content whether by direct or indirect methodologies lead to the generation of many applications in civil engineering which assist in the design, maintenance, and construction of various projects.

In large scale projects, the integration of thousands of construction site images stored in site photographs and logs is a significant part of the construction documentation. However, identifying and locating such data which is required for the decision-making processes is a time-consuming and a very hard task. Therefore, efficient construction information management requires automatic methods for the incorporation of construction images.

Brilakis (2005) explored processes for retrieval, classification, and incorporation of construction images in the model based Engineering, Architecture, Construction, and Facilities Management AEC/FM systems. A mixture of techniques from the areas of information retrieval, computer vision, image and video processing, statistics and content-based image and video recovery have been used to develop a methodology for the retrieval from components of a project model the related construction site image data. This method was tested on construction site images available from different sources of both past and present projects in building construction and transportation. It proved to be able to store, classify, integrate and recover image data files in inter-organizational systems automatically allowing their usage in project management related tasks.

Common knowledge might indicate that the temporary nature of the construction site excludes sophisticated production monitoring systems from being installed.

Sacks et al.. (2005) tested this concept's feasibility. The results show that, contrary to the above, a sophisticated system is technically possible. This system has the potential of providing real-time, exact, and low-cost project control information. Monitoring of production progress, quality, and cost when done manually result in being approximate, expensive, and delivered with a time lag thus preventing an effectively closed control loop. A system concept was developed for automatic monitoring of construction lifting equipment using a "black box" monitor and a building information model. The system provided useful feedback information which could be used for project management.

Shihet al.  (2006) developed a panorama image database management system (PIDMS) for the management of construction records. The system used panorama cameras to record videos and panorama images which were used for the assessment and management of manpower, schedule, machinery, and materials. The system users of contractors, system site managers, construction site managers, designers, and draftspersons can log into it through a browsing interface. The system is created according to explicit functions such as real-time monitoring, image labelling, video indexing, working drawing browsing, and construction recording. The system was applied to real-time panoramic observation of construction sites in which the videos and panorama images were used as maps for an Internet communication platform. This platform was made up of daily records serving as a panorama based information system. It was shown that the PIDMS increases the effectiveness and efficiency of supervision.

Also, Brilakis and Soibelman (2006) presented a model for image retrieval interfacing with the management structures established construction data. This model retrieves the images by using related objects in project construction databases or models. The related objects are date, location, and material information extracted from the image content by the technique of pattern recognition.

Systems looking at buildings have generated over the years a dynamic research area in the field of computer vision. The attempted tasks include basic presence detection, recovering position by model based fitting, form 3D recovery, and properties image based analysis. Lukins and Trucco (2006) presented a thorough background of current computer vision techniques focusing on building and showed how they can be utilized to address the need for looking at dynamically changing structures. The driving force behind this is the need of the construction industry for comprehensive automation regarding the tracking of changes and progress made related to large scale projects. They also highlighted the challenges surfacing from this task with a first prototype system, and presented further guidelines for research to which computer vision could be applied for the evaluation of construction progress.

Manual appraisal of construction projects progress is irregular and subject to errors. Images of sites are exceedingly cluttered and common with shadows, occlusions, people and equipment rendering them hard to analyse.

Lukins and Trucco (2008) presented a first prototype system that is able to detect building site changes by the output of a fixed camera. These changes are classified as being either an actual structural event or as unrelated. They have examined a prior building model to align the camera and the scene in order to identify regions for images where building components are expected to be seen. This enables the homing in on major change actions and checks the presence of a specific element.

Trinh et al. (2008) described an approach for building surfaces recognition in which the natural characteristics of a building image are extracted. These characters are fading points, surfaces, wall area, areas, and a list of feature vectors. They are used to describe a building's model by being arranged as a hierarchical system of features. After the organization process they are stored in a database. The characters of a new image are worked out in the same form within the database. The new image is matched up with those in the database in order to select the best fit candidate. The correct match is verified by a cross ratio based algorithm and is used to update the model of the building. Figure 2.3 shows an overview of the method.

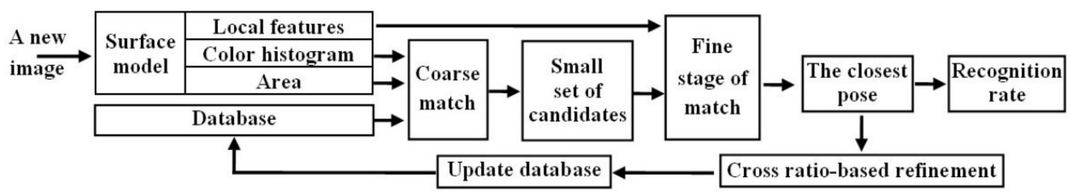



Figure (2.3): Image recognition Model (Trinh et al. 2008).

The proposed method was applied to perform the recognition of 50 buildings under the same general condition in Ulsan metropolitan city in South Korea. The experiment illustrates that the method achieves a decrease in the size of the database in addition to obtaining high recognition rates. It also showed that the problem of various buildings can be solved by the separate analysis of each surface of the building.

Memon (2008) presented the Automated Construction Project Progress Monitoring (ACPROM) (Figures 2.3 and 2.4), which is prototype export system developed for the integration of construction drawings, construction schedule, and digital images related to construction site progress. This model reengineers the traditional AEC field inspection process which is obtained by the automatic interpretation of the CAD drawing of a given building, extracting the data of its structural components, developing the data base and at the same time extracting the digital images information. By simulating the two databases, the progress percentages are calculated and the bar chart of the actual physical progress is developed automatically.

ACPROM facilitates the storage in an integrated construction related data-base management system of structural design information which can then be shared by a range of computer applications. ACPROM model constitutes a part of the Tele-Construction base site management system, which retrieves the status of the current construction work and generates the actual work progress bar-chart. The monitoring of the progress application of the ACPROM model enables project management teams to improve the tracking, quality control, and productivity of construction projects together with improving the decision-making process.

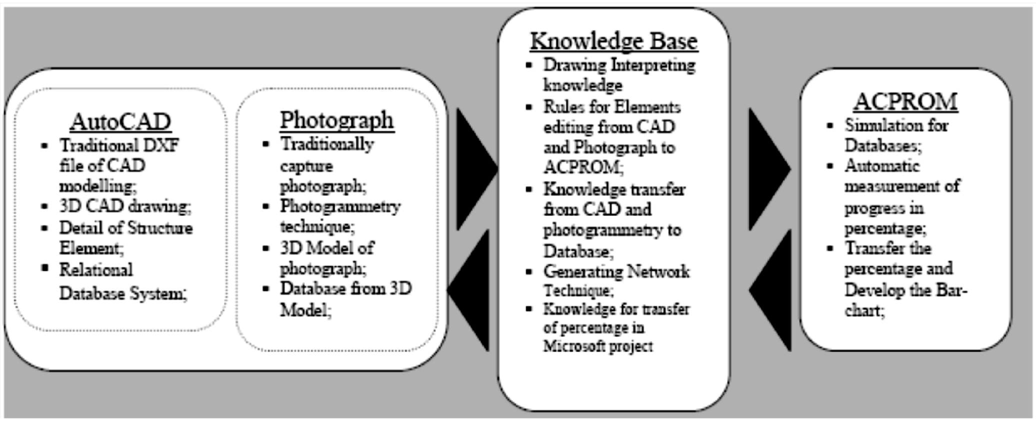



Figure (2.4): ACPROM Components (Memon, 2008).

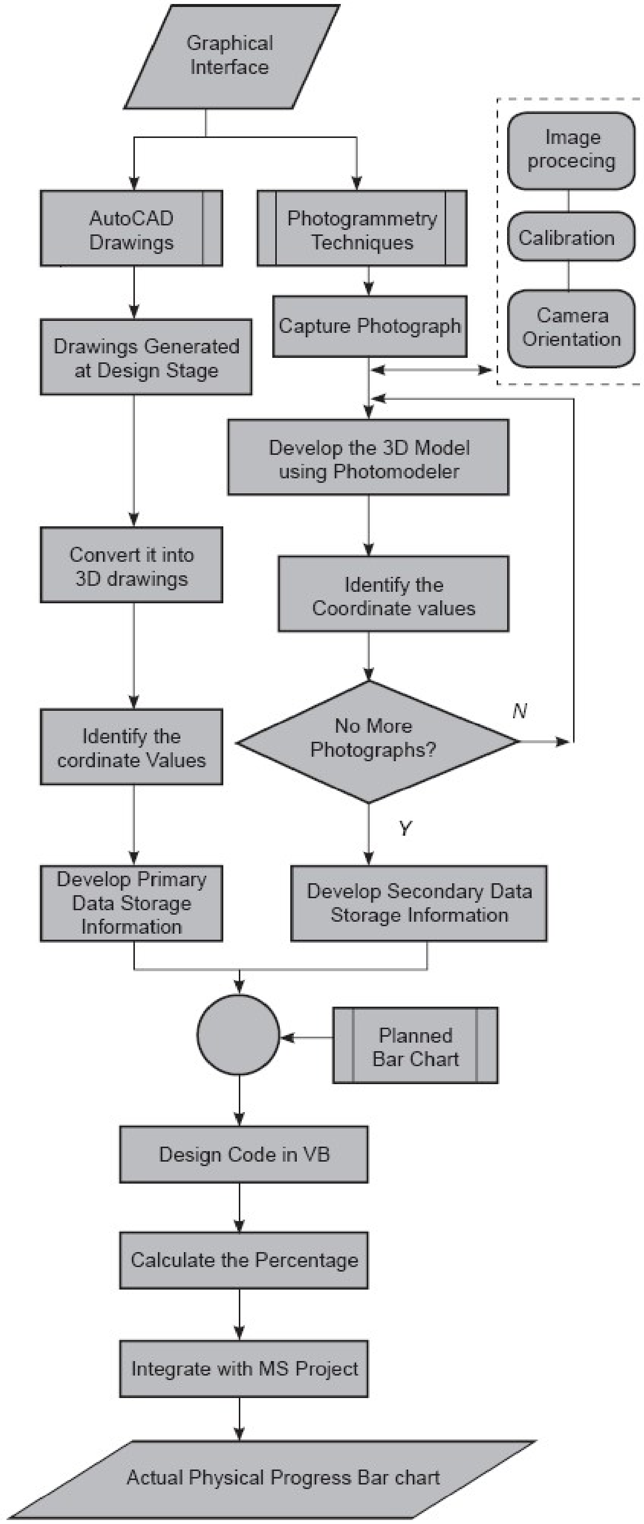



Figure (2.5): ACPROM Flow Diagram (Memon, 2008).

Rebolj et al. (2008) described integration of two independent systems that perform automatic on-site data collection. Both systems are using the same 4D model as a source of basic information, but are monitoring different aspects of a construction project: the first system is tracking construction activities using on site images and outputs the actual start and end time of performed activities, while the second system is tracking resources. They also, focused on improving reliability of both systems with consistency cross-checking of their outputs. The approach reduces the latency between the acknowledgment at project management level and the occurrence of an event. Also, it brings better project control by reducing the possible adverse consequences on project schedule and budget.

Pardasani et al. (2009**)** described an internet based prototype tool located at a construction site and outfitted with wireless Ethernet for locating structural steel components. They also verified the incorporation of the design data and the bill of ladings within location tracking. The integration with the design data can assist the field staff to recognize the main characteristics such as length, width, weight… etc. This knowledge helps to identify quickly from a distance the desired parts as the field staff get closer to the indicated location. The manufacturing status of a part can be known from integrating with upstream applications such as fabrication or scheduling. Moreover, the functioning of the system used in materials handling as a whole can be upgraded by incorporating decision support systems such as crane dispatching, routing, and materials storage layout in the location data.

Distante et al. (2010**)** presented a wide dataset acquired by a state of the art range camera for the purpose of indoor surveillance applications. The main issue faced is the definition of common basis regarding the comparative evaluation of the performance of vision algorithms.

Textured surfaces are part of the natural surroundings requiring the development of efficient applications of computer vision algorithms with precise surface descriptors. These surfaces present local height variations together with variations of colour or reflectance and are referred to as a 3D texture. As the lighting and viewing conditions are varied, effects such as occlusions, foreshortening and shadowing result in significant changes in texture appearance. Accounting for these variations of texture appearance resulting from changes in imaging parameters is important in developing accurate 3D texture models.

Cula and Dana (2004) constructed a BTF-based surface model which is based on capturing the variation of the fundamental statistical distribution of local structural image features when the conditions of viewing and illumination are changed. This 3D texture representation, which is called the bidirectional feature histogram (BFH), was employed to design a 3D texture recognition method that classifies surfaces based on a single original texture image of unknown imaging parameters. A computational method for quantitatively evaluating the relative significance of texture images within the BTF was also developed. The performance of the methods is appraised by using over 6200 texture images equivalent to 40 real-world surface samples from the CURaT (Columbia-Utrecht reflectance and texture) database. The experiments showed excellent classification results, which validate the strong descriptive properties of the BFH as a 3D texture representation.

Rosenhahn et al. (2005) discussed the 2D-3D pose estimation problem of 3D free-form contours by observing items of any 3D form in a calibrated camera image. Pose estimation of a 3D object means the estimation of the comparative position and orientation (including a rotation Rand translation T) in regards to the reference camera system (figure 2.6). The blending of modelling free-form contours within the pose estimation problem is obtained by conformal geometric algebra which represents units as stereographically projected entities in a homogeneous model.

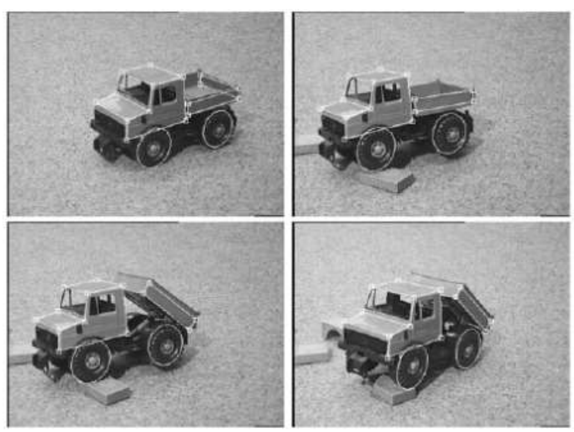


Figure (2.6): Pose Estimation by Using Different Types of Correspondence (Rosenhahn et al. 2005)

Blais and Beraldin (2006) proposed a three-dimensional multi-modal laser scanning system which merges high-accuracy 3D laser imaging, very high-resolution perspective colour projection, and on-site geometric calibration of the intrinsic and extrinsic parameters. Motion adjustments directly obtained from the range measurements using ICP and a 6-DOF self-built model tracking were used to do away with the need for external positioning sensors and stable mechanical structures. The intimate link between scanner modelling, performances, and visualization was demonstrated and thus should be taken into consideration as an integral part of the modelling chain (Figure 2.7). This has a special importance in the field of heritage where the acquisition must adapt to the environment. Charts and equations are shown to arrive at the most favourable configuration of the laser scanner and colour camera and for a 3D modelling product regarding the camera settings such as focal length, best lens aperture, total range depth and optimum range.

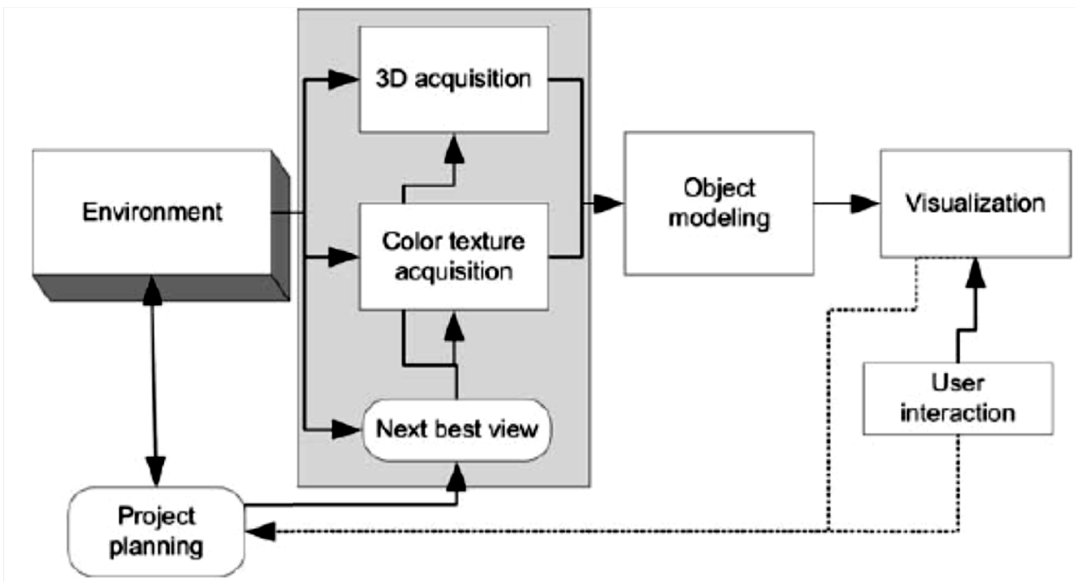



Figure (2.7): The 3D Acquisition and modelling Chain (Blais and Beraldin, 2006)

The NIST Construction Metrology and Automation Group is carrying out a research to provide performance methodologies, metrics, and standards assisting in the improvement of advanced automated systems of construction activities. Research efforts by Lytle and Saidi (2006) produced an automated construction test bed which demonstrated a robotic steel erection sequence prototype implementation. They presented a summary of an independent arrangement of a multi-component test steel structure compiled by combining the employment of a pose tracking robotic crane equipped with a laser-based site measurement system, with assembly scripts generated from a commercial 4D CAD package.

Sequeira et al. (2007) described a system whose input is multi-sensory variable scale data. The varying scale allows for different algorithms and acquirement systems according to the size of the site, building, or object to be modelled. The comparison between approved design and "as-build" models was achieved by semi-automated tools. Examples of outdoor and indoor environments were presented and showed the possibility to redo a data acquisition at any time and from the same area without any undertakings of exact orientation, position, or used scanner. Thus, it is possible based on this new information to detect decimetre to millimetre variations in the scene. The research incorporates the implementation of the 3D modelling and verifications tools in security planning including preparation and training of rescue operations, the assessment of vulnerability of public areas, and disaster assessment and remediation.

The results of these indicate the possibility of merging data from several sources, including various depth accuracy and resolution, spatial resolutions, types of equipment, capture points and orientations, and data sets obtained at different moments of time.

The technique allows an easy and a fast approach of modelling and documenting of wide areas which can later be used as reference models or training tools for inspections preparations. Precise area, mass, and volume measurements can be obtained from these models due to the fact that all 3D data is based on exact distance measurements. These measurements can be linked with data from other sensory (e.g., radiation) equipment.

Self-assembly is the development of complex structures by combining small separate subunits at an energy minimum. Most of the approaches related to micro scale self-assembly use hydrophilic- hydrophobic relations for the assembly of the subunits. However, this approach can be used techniques to develop a few numbers of shapes defined by the borders between the different phases.

Fernandez and Khadem-Hosseini (2010) introduced a technique where a template acting surface directs the assembly process by partially restricting the subunits by confining them. They used a versatile and commonly used elastomeric material (poly dimethyl siloxane PDMS) which can easily be moulded to duplicate the topography and shape of many 2D and 3D structures.

Al-Kindi and Khleif (2010) proposed a technique to re-construct and acquire3D objects utilizing shadow data. The proposed technique is capable of extracting object height features that are not directly visible to the camera scene for the directions associated with the generated object shadows and incident light only, hence, acquired height features represents the object features that have actually obstructed the incident light.

It became clear from the reviewed literature that image recognition techniques and systems were extensively used in construction and their benefits are widely recognized. This fact gives further confidence to incorporate image recognition in construction safety training and recording systems.

### *2.6.3 Image Recognition in Construction's Health and safety*

Caldas et al. (2006) developed an algorithmic framework for path planning and avoidance of obstacle. The algorithms were based on three-dimensional real-time job site models for the purpose of improving equipment operation safety. They have the capability to prevent collisions between on-site objects and heavy equipment vehicles. In order to arrive at a collision free path, algorithms were developed and integrated for real-time 3D spatial modelling, avoidance of obstacles, image data acquisition and finding the shortest path.

Teizer et al. (2007) introduced a newly developed technology called Ultra Wide Band (UWB) for resource tracking and real- time location sensing. This technology is used as a data collection tool, preliminary data processing algorithms, and experiments.

Teize (2007) presented a framework implemented to create technologies and data processing algorithms for accurate and timely construction related information. Data collection technologies and developed data processing algorithms are introduced to show the benefits in which the field of construction can gain by supplying project managers and field personnel with automatically generated information for applications such as project progress monitoring, active safety, tracking materials, etc.

Teizer (2008) presented a review of the construction safety problem and focused on automatic data processing algorithms and data collection devices which can be part of a construction applications' safety system. He used relevant technology applications to gather and process safety data within construction sites introducing the terminology to a 3D imaging system called 3D Range Imaging Camera. The Camera permits gathering entire scenes (thousands of objects' range points) at update rates which are equal to video. These ideas assisting the generation of precise calibration methods for 3D Range Imaging Camera were discussed and the results showed the restraints and advantages of this technology.

There is a high risk of unintentionally damaging the existing underground utilities during a typical excavation operation. These incidents cause project's financial loss and can stop or delay its construction. They may also create a life threat which results in accidental deaths.

Behzadan and Kamat (2008) discussed the applicability of tracking and advanced visualization technologies to improve the safety of works in sites of projects' construction through the increasing of the visual observation of the operators of construction equipment. The Global Positioning System (GPS) and the integration of Augmented Reality (AR) visualization are investigated to develop excavation site's real-time views. This view is created by superimposing the CAD models of the underground utilities over real world's live video streams and presenting them to the operator of the equipment in real time.

Chi and Caldas (2009) presented a project regarding the development of an automated assessment of safety framework for surface mining and earthmoving activities. It seeks to identify and collect the needed data to perform the safety assessment and utilizes the gathered data to provide more knowledgeable and efficient safety in the decision-making process. An automated safety assessment method based on the identified data needs, was then developed. Preliminary results showed the feasibility of proximity estimation as well as object identification and tracking, which can be used for automated safety assessment (Figure 2.8).

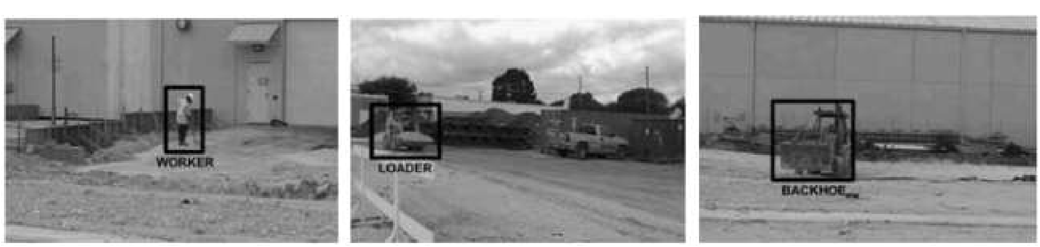



Figure (2.8): Object Identification and Tracking (Chi and Caldas, 2009)

Gonsalves and Teizer (2009) presented a real-time system for the surveillance and tracking of construction workers in a work-site for health monitoring and safety purposes. The workers' safety is continuously monitored by marking the target with a particle filter and following it in the work-site. A star skeleton structure was used to model the worker and motion analysis was conducted to determine the variation in angles between the different segments of the model. The designed system uses a 3D range image camera applying distance based information to slice a specific target from a scene. This process will provide segmentation in 3D space, detection of multiple workers, and monitor and track and each one of them separately.

The reviewed literature was seen to concentrate on monitoring rather than training to manage different site hazards. This is a further demonstration to the need and relevance of utilizing the image processing technology in the safety training of labour to enhance construction site safety.

## 2.7 Animation in Construction

The subject of animation is related to this project by the fact that it is envisaged to generate safety training videos for selected site construction activities. After a general introduction to the subject it shall be addressed in relation to the applications of animation techniques in construction training and the use of animation in construction health and safety.

### *2.7.1 Introduction*

Since more technologies become available and construction projects become more complicated efficient communication becomes essential and computer graphics animation can perform an important role in the industry. Computer graphics animation and three-dimensional CAD were operated on EWS (Engineering Work Station) or GWS (Graphic Work Station).

The importance of computer animations stems from the fact that it facilitates the integration of engineers' expertise on site with the relevant systems of design and construction management thus resulting in the improvement of quality and productivity. The improvement is a result of the speed and efficiency of the inter communications between the various organizations of the engineers, constructors, and clients. The virtual environment created enables easy and clear comprehensive and interactive viewing of design objects and facilities.

Yoshihiko (1994) evaluated computer graphics animations role and purpose in construction management being an important tool in the computer integrated construction activity.

Hurrion (1993**)** Highlighted the significance of computer graphics in the encouragement of communication between all relevant professionals within the vicinity of the sites which results in saving wasted time and money due to the misinterpretation of design, information imprecisely transferred from drawings, use of outdated versions of plan, and lack of coordination. He concluded that a substantial improvement in productivity, quality, and successful completion of projects can be achieved when applying computer graphics animation.

James et al. (1993) described the two function types of computer graphics animation as being real-time animation and frame accurate (frame-by-frame) recorded animation.

Real-time animation is dynamic and interactive thus require substantial graphics processing power. The process of producing real time animation is composed of four steps the first of which is by using an external CAD or similar animation software for the construction of three-dimensional models which are then loaded into the animation system. The third step is for a user to provide a real-time animation control such as camera position, view parameters, and object positions in the model. The last step is the rendering process after the camera and the objects are moved according to the input provided by the user. The important aspect of real-time animation is its capability to present total interactive control over the motion of the camera and the objects.

The frame-accurate (frame-by-frame recorded) animation is not an interactive process. This fact reduces its effectiveness for interactive applications such as construction simulation and design reviews. However, the process of frame accurate animation is comparable to that of real-time animation. It starts with the formation of three-dimensional objects and saving the movement of the objects and a camera in a key frame in a script file. The system will render and record the scene then moves to the next frame. The process repeats itself until the motion script files defined by object and camera are all completed.

Improved automation and integration of the decision-making process can provide a usable and machine-readable information environment in which efficient construction management processes computerization can be achieved.

Miyatake and Kangari (1993) claims that successful implementation of computer integrated construction (CIC) depends on:

1- Cooperative not competitive business relationships integrated computer systems that allow sufficient field access and concurrent design and construction.
2- Ability to offer operators and owners with information required for maintenance and operations;
3- Electronic communications with major project's participating parties such as vendors, subcontractors and clients.

Euler (1993) defines the objective of CIC as the vertical incorporation of data, knowledge and design decisions during construction project's phases resulting in the improvement of quality and productivity of design and construction. The facilities constructed by utilizing this approach will be able to meet the technical performance and cost schedule objectives.

Yoshihiko (1994) state that the use of computer graphics animation for the purpose of Collaborative Integrated Communications for Construction visualization has the following advantages:

1. The ability to interactively and directly display design ideas in a form representing physical and real images.
2. The ability to simulate a time-eventing function by joining it to construction planning packages of other personal computers.
3. The ability to construct a project on the computer screen before construction in the site avoiding unseen flaws.
4. The capability of involving more people from management, design, operations and construction during the design phase to explore options leading to design improvement.
5. The ability to provide clear and instantaneous communication regarding spatial relationships between designs objects resulting in better installation sequencing.

Yoshihiko (1994) showed that computer graphics animation could be applied during the construction phase of a highway reconstruction project. The application was used to assess the constructability of a number of bridges knocking down processes on the computer screen. It facilitated the involvement of all participants, including the client to understand each other's work and feel comfortable with the entire process.

Wallner et al. (2010) stated that the basic idea of four-dimensional (4D) animation approaches is the establishment of a link between an executed construction task and the component where the task is being executed.4D CAD is being used more and more in civil engineering projects however, the present approaches accept the existence of traditional scheduling and 3D CAD where tasks are stored in scheduling tools and components are stored in CAD tools.

### *2.7.2 Animation in H&S Construction Training*

Theoretical training constitutes the greater part of health and safety trainings presented to construction workers. The majority of the construction workers have a low education standard. This fact results in that learning the health and safety ideas delivered by theoretical training methods becomes hard for these workers. Therefore, alternatives such as dramas and animations have the ability to make trainings more appealing and enjoyable and can overcome this problem.

The construction industry has a bad safety record compared to other industries. Some of the main causes of accidents in construction sites are attributed to the deficiency in adequate training and know how about site health and safety issues. The lack of training is an indication of the weak safety and health management by the companies. Thus, implementing an efficient training program by the construction companies has a great possibility minimizing such accidents Arslan and Kivrak (2009). They give an overview of an ongoing study aiming at preparing dramas and animations which present construction accidents. These visual materials can be used as health and safety learning tools for trainings in construction industries to minimize accidents.

Hick (1997) listed the common advantages and benefits of the animation in construction training as:

- Talent and capability improvement: It is a proven fact that the percentage retention of information is higher when presented by animation in comparison to classroom lectures.

- Engagement: Interactive learning with live-action animation, reinforce skills and keep learners interested. It persuades learners to return to the program.
- Flexibility and Safety: Ability to train workers without being physically exposed to hazards.
- Motivation: Animation is an interactive way for flexible training and education thus motivating participants to learn more and get more skills.
- Practicality: Capability of presenting true-to-life daily situations hence allowing learners to learn-by-viewing, doing, or coaching.
- Consistent: All learners become skilled at the same principles and skills.
- Attracting and holding attention: Animation is useful in holding an audience's attention and can create emotional response during training.
- Displaying designs and Safety operating methods of complex equipment: It offers the showcasing a quick animated tutorial of the safe methods recommended for operating complex equipment.
- Showing processes or relationships: Animation can demonstrate relationships and processes that are impossible to observe in reality such as electric shocks.

## 2.8 Summary

The extensive literature review conducted before embarking on this research project was intended to establish the need and relevance of an automated interactive construction site knowledge management and safety training tool making use of a set of digital photographs of an existing building as input data. The subject of health and safety in construction was investigated and was found to lack systems dealing with safety training. A further area which was discovered to require attention was that of computerized work reports generation including daily safety reports which can serve as a knowledge management data base.

In order to target the project at the most important activity from the safety point of view, the survey pointed to steel construction as the most hazardous activity requiring special attention. This activity exists during the temporary and the permanent phases of the project which is a fact recognized and addressed in the developed safety model as shall be seem later.

The fact that construction companies in this age of globalization are operating worldwide resulted in cultural and language issues which need to be dealt with. Vision based training was determined as the solution to these issues and was reviewed.

The review also confirmed that training can reduce accidents and save money. It also showed that a proactive approach needs to be adopted.

The available data which is constituted from a digital image set needed to be analysed and a suitable approach of image recognition needs to be identified. For this purpose, the available literature on image processing and recognition was reviewed.

The image processing which required comparisons with the 3D project's digital design generated a 4D platform which can be utilized in other forms of project knowledge management. The survey of knowledge management systems indicated that the BIM is the model most suitable for construction activities which lead to a more focused review to determine how it can be incorporated in a future upgrading of the developed model.

In conclusion, the review established the following:

- The subject of construction health and safety is important from human and financial points of view.
- Steel construction is a suitable topic for targeting being particularly hazardous and easily identifiable from digital photos.
- Training can reduce accidents and a proactive vision based training model is suitable in overcoming cultural and language problems.
- There is no available proactive vision based real time computer program applications related to construction safety.
- Safety reports storage and retrieval can provide a base for a highly-needed knowledge management system.

# Chapter 3- Health and safety

## 3.1 Introduction

Construction sites remain to be a hazards source for those on sites and other members of public. Workers may suffer from work related illnesses and possible fatalities while the public and especially children can be injured by exposure to badly controlled work activities. The duty to act responsibly in preventing unsafe practices lies with everybody related directly or indirectly to the working activity. Accidents can happen to everyone and none is spared from this probability hence careful consideration must be given to work decisions in a manner to eliminate these unsafe practices.

Safety is not just about its human side of caring for the health and wellbeing of workers. It has a significant financial side in the cost of downtime, insurance and lost man hours.

Simple precautions can result in reducing accidents or lowering their impact. Suitable protective clothing, following basic health recommendations, maintaining the site clean from debris and first aid knowledge can be effective in improving the working safety environment. Another important factor is providing proper specific training to the workers related to the jobs assigned to them.

This chapter concentrates in more depth on the subjects summarized in chapter (2) of this thesis. This is due to the fact that these subjects are going to be the main components of this research activity. In this respect, this chapter aims at understanding the construction site health and safety principles, the parties responsible for their application, and how can the performance of health and safety be improved. This understanding is essential in identifying the associated hazards related to the various stages of project execution.

The steel erection activity was chosen for a more detailed investigation due to the high number of related hazards. This is also the reason why it was selected for modelling in this project.

The use of training videos and animations, which is one of the objectives of this project, is reviewed in order to be incorporated in the project's model.

Finally, accidents investigation is briefly introduced as it can be the subject of a possible future extension to this research.

## 3.2 Role of Health and Safety in Construction

It is a common mistake to conduct the Health and Safety exercise in order to comply with the related laws and regulations. This approach is wrong and unethical especially in the construction industry. Although this industry accounts for 5% of the general working force, it results in 22% of the fatal injuries and 10% of major injuries which are substantially bigger than its share indicating its dangerous nature (Health and Safety Executive, 2013).

Falling objects, moving vehicles, collapse s, and electrical shocks were the major causes of fatalities; while slips, trips, falls, and mishandling were the causes for major injuries.

The role of Health and Safety in construction sites should not be limited to the protection of workers but should be extended to cover the general public directly or indirectly in contact with these sites. An important objective of this role is the strict enforcement of the relevant laws and regulations. A significant reduction in fatalities and major injuries is being witnessed over the last years due to the improved adherence to guidelines and regulations as reported in the UK's Health and Safety Executive statistics and publications (Health and Safety Executive, 2013).

### *3.2.1 Importance of Construction Safety*

The importance given to the Health and Safety aspects in any construction project is due to several reasons such as the provision of a safe working environment which leads to employee's welfare, and construction cost control. While the first reason is clear to owners and contractors the later is usually overlooked. The estimated project's cost can be better controlled when risk and hazards are reduced or eliminated. Costs overrun will result in diminishing the profit margin of the contract and renders it not attractive hence a dedicated commitment by all parties involved in any project will significantly impact its profitability (Emmons, 2006).

### *3.2.2 Health and Safety Principles*

Health and safety should be regarded as one of the key targeted objectives in any business and particularly in the hazardous construction industry. However, following and abiding by the various rules, regulations, and guidance associated with its implementation can prove to be a relatively complicated task for construction management teams. In order to simplify the understanding and implementation of the relevant H&S rules it might be conducive to consider the underlying principles behind them (The ROSPA Occupational Health & Safety Awards, 2002).

These principles fall under the following titles:

i) Health and Safety Management System:

A system should be in place which includes designations, policies, and work procedures. This system should clearly define accidents preventive measures and designate a person or persons whose job is to enforce compliance with H&S rules and deal with any possible legal obligations. The system should also set out clear steps for planning, monitoring, and controlling these measures.

ii) Hazards identification and risk assessment:

The process of risk assessment associated with the works' identified risks should be carried out in logical steps leading to the establishment of an approved system which helps to address these issues. These steps can be as follows:

- The identification and documentation of any activity which has the potential of causing harm to the workers or the general public.
- The estimation based on previous records of the probability of causing harm by the identified activity and level of severity of such harm.
- The establishment and enforcement of an adequate measures response protocol to the identified risks which should be updated and maintained using the relevant bench marks set out in the applicable Health and Safety Laws and Regulations.

iii) Informing and training workers to understand and apply these measures:

The implementation of Health & Safety guidance, regulations, and recommendations related to any specific type of work is a joint responsibility. The first step in this coordinated effort is between the work force and its safety designated staff. It is the Health and Safety departments' responsibility to establish a sense of commitment to safety practices in all members of the working force. However, it is not enough to restrict the Health and Safety education and coordination to the immediate work site. Customers, clients, contractors, suppliers, and other related groups should also be involved in this effort. Furthermore, the implementation of Health and Safety regulations and r5ecommendations should not be in response to accidents. It should be a proactive exercise which prevents accidents rather than respond to them. (The ROSPA Occupational Health & Safety Awards, 2002).

### *3.2.3 Construction health and safety responsibilities*

Health and Safety in the construction industry should be the main concern of all parties within a specific project and outside related. The parties within the project include both its employees and employers while the outside bodies are clients, the government, and the independent regulating authorities.

The main responsibilities of each party are: (Kheni et al., 2008) and (Laryea and Mensah, 2010)

- Employer/Contractor: To provide safe access, working procedures, tools and machinery, storage, fire safety, and people's protection.
- Employees: Abiding by safety rules and following safety guidelines, operating equipment as per manuals, and reporting defects and possible hazards sources.
- Client: Employ qualified contractors, ensure that a health and safety plan is in place, ensure the availability of site welfare facilities, and ensure adequate public protection.
- Government/Agencies: Providing and enforcing Health and Safety law and guidance notes, health and safety education, and safety alerts.

### *3.2.4 Costs and effects of workplace accidents*

Work place accidents result in financial losses due to ill health and psychological effects. Hrymak and Perezgonzales (2007) summarized the likely cost variables and their description in table (3.1):

Table (3.1): Cost Variables. (Hrymak and Perezgonzales, 2007)

| **Cost variable** | **Description** |
|---|---|
| Fatalities, injuries and absenteeism | Cost of lost work time, production, fines and legal payments |
| Staff turnover | Replacement training and recruitment costs |
| Early retirement and disability | Costs associated with retirement, fines and payments to the injured person |
| Non-medical rehabilitation | Counselling, retraining and workplace changes |
| Administration duties | Time and effort spent investigating the accident |
| Damaged equipment | Repair and replacement costs |
| Insurance premiums | Any increases, refusal, changes in cover or conditions attached |
| Legal liabilities | Fines, regulatory activity, settlements and associated fees |
| Lost production time | Losses in production |
| Opportunity losses | Lost orders, inability to start or finish orders on time |
| Present income losses | Loss of income from present and second jobs |
| Loss of potential future earnings | Loss of income from present and second jobs |
| Expenses not covered | Medical, travel, new clothing |

The authors also identified and described the major psychological effects as in table (3.2).

Table (3.2): Major psychological effects. (Hrymak and Perezgonzales, 2007)

| Effect | Description |
|---|---|
| Health | Hospitalisation, medical care, permanent disability, rehabitation |
| Quality of life | Life expectancy, quality and disability adjusted life years issues |
| Grief and suffering | To the injured person, their friends and relatives |

Cormak et al. (2006) produced evidence-based data gathered by three different methods on the negative impact of accidents on workers' and their families lives. Two hundred telephone interviews, eighty home based interviews, and forty follow up interviews resulted in establishing a relation between workplace accidents and the wellbeing of individual workers and their families who found their lives significantly affected by these accidents. These adverse effects were psychological, behavioral, and social.

### *3.2.5 Role of Health and Safety in Steel Structure Construction*

The Health and Safety policies in Steel Structures construction are the mutual responsibility of employers and employees.

The management of Steel Structures Construction must observe its responsibilities in: (ASA, 2007).

- Providing and maintaining safe and healthy working conditions.
- Provide training and safety instruction.
- Maintaining a continued interest in Health and Safety.
- Observing all Health and Safety statutory requirements.
- Consulting employees in Health and Safety related matters.

Similarly, it is the employee's duty to follow and implement the Health and Safety Policy by:

- Working safely
- Reporting incidents.
- Following safe work system procedures.

The Occupational Safety and Health Administration (OSHA) conducted a study regarding the circumstances that led to fatalities among steel construction workers. The study recommended erection rules related to the work site layout and the erection plan based on engineering and regulatory guidelines that will largely prevent fatal accidents.

## 3.3 Health and Safety in Construction Sites

Technological advances played a mixed role in regards to the Construction Industry. While certain aspects made working sites a safer and a healthier place, others contributed to the increase in number and in the seriousness of daily confronted hazards. The main areas of these technical advances are: (Heng, 2006)

1- Inanimate power: The modern construction industry tools operated by electricity, hydraulics, steam, pushed the limits of the operating power bringing alongside a higher level of associated hazards.

2- Machines: Operating machines on construction sites without the proper training of the operators can render them dangerous pieces of equipment capable of inflicting harm and damages.

3- Materials: Some new construction materials require special care due to their toxicity or impact on health if handled without the proper safety instructions and procedures.

4- Work specialization: The nature of the work activities in a modern construction site require high specialization in each field in order to improve efficiency, however it decreases knowledge and awareness across fields. This task concentration is a source of hazards when a verity of works is being carried in the same location by several specialties.

### *3.3.1 Improving Health and Safety Performance*

The Parties involved in the Health and safety of Construction Sites including Governments, Organizations, and Regulators have an important role to play in improving safety records of the Construction Industry which remains as the most hazardous industry in terms of work related accidents.

The Key improvement areas are: (Health & safety Executive, 2003)

1- Culture

The culture which resists embracing developments and new ideas is not an easy one to change. This is not a problem specific to the construction industry and cannot be tackled as an isolated case. Continuous, serious, and hard interaction between management and the work force can result in the gradual erosion of this attitude.

2- Education, training and competence

Workers within their specific sphere of activity should be competent in regards to Health and safety as well as in their work activity. Integrating Health and Safety subjects within the training programs of construction professionals will help in arriving at this level of competence.

3- Clients

Clients' agendas should be focused on best value and not cheapest value products and in doing so they become a driving improvement force.

4- Integrated teams and management

Integrated teams linking design with construction are more likely to embrace Health and Safety improved performance alongside the improvement of project management being their best feature.

### *3.3.2 Approaches to Health and safety improvements*

A review of the construction's Health and Safety improvement subject identifies the following approaches:

1- Personnel Selection

It was noted that a small number of employees in any company are responsible for a large percentage of its work-related accidents which lead to the belief that by screening employees according to some related variables the total number of accidents can be reduced. However, all the different selection techniques adopted failed to show an improvement in occupational safety and hence establish a relation between worker's characteristics and work accidents (Bhattacharjee and Gosh, 2011).

2- Technological Intervention

Technological interventions are manifested in automation, Karwowski et al. (1988) and in overall facility redesign, Kjellen (1990). However, new interventions are usually associated with human errors related to their introduction, Guastello, (1993). For example, automation interventions may result in reducing accidents, but can generate risks associated with their implementation, Chignell et al. (1986). New protective measures were introduced such as emergency stop switches, Sjostrom, (1990) sensors detecting workers' presence in an unauthorized space, Malm and Souminem (1990).

Specific construction operations can benefit from technological interventions such as robotic pipe laying, Bernold et al. (2001), The benefit is reflected in the reduction of accidents and cost due to the elimination of human related working safety procedures (Li and Bernold, 2005).

3- Behaviour Modification

The modification of behaviour is achieved by a training program of safety information and safe behaviour. The training program is then followed by an observation and feedback period. Guastello (1993), Sulzer-Azaroff and Austin (2000), and McAfee and Winn (1989) reviewed the behaviour modification programs and recorded variations incorporating the providing of incentives, goal setting, and monitoring by using mechanical aids. Loafman (1996)**,** justified focusing on employee's behaviour as being a critical factor in arriving at better safety performance.

4- Poster Campaign

Saarela et al. (1989) chose a ship yard site to study the effects on safety of poster campaigns. The study followed the criteria of a campaign proposed by Hale and Glendon (1987). The random interviews with selected employees concluded a limited effect of the campaign; however, there is evidence to the contrary arrived at by Kaestner et al. (1967). The effects of poster campaigns might not be reflected in accidents prevention but rather in increasing workers' awareness (Saari, 1998).

5- Quality Circle

The Quality Circle is a group of employees with similar types of works who meet to discuss and solve matters related to productivity and product quality Guastello (1993). It was also established that quality circle techniques do help in preventing accidents (Saarela, 1990).

Rosenfeld et al. (1991) based on field experiments concluded that construction projects quality circles help in improving the safety of workers together with some monitory savings.

6- Exercise and Stress Management

Gebhardt and Crump (1990) proved the success of exercise programs resulting in the reduction of stress related injuries in physically demanding jobs, Cady et al. (1985) established that exercise programs have positive results in minimizing fire fighters work-related injuries.

Many constructions related exercise sessions were developed in order to warm up cold muscles before starting to work, (Wolff, 2009).

Ivancevich et al. (1990) conclude that stress management programs proved to be successful in reducing stress and hence improve job attitudes. However, Murphy (1984) pointed out the limitation of the stress management programs which do not target the elimination of the sources of stress but concentrate on educating workers to cope with it.

7- Reporting Near-miss Accident

Guastello (1993) shows that approximately ten near misses have occurred for every real accident. Thus, reporting these near misses provide a better opportunity to devise preventive measures. However, Carter and Menckel (1985) showed that accidents rates were not reduced with respect to increasing corrective suggestions. Although the accidents' frequency rate was not significantly affected, the injury severity was observed to be reduced.

8- Safety Climate

Williamson et al. (1997) defines the safety climate as a "summary concept describing the organization's safety ethic which is reflected in the safety beliefs of employees that can predict the way employees would behave with respect to safety in the workplace"**.** Dedobbeleer and Beland (1991) conducted a study and suggested that the two important factors which have an impact on the safety climate are the workers' involvement in safety and the management commitment to safety.

9- Zero Injury Technique

Hinze and Wilson (2000) generated five techniques designed to help contractors and owners arrive to a point of no accidents on their construction projects. The generated techniques were: safety orientation and training, pre-project planning for safety, alcohol and substance abuse programs, written safety incentive programs, and accident/incident investigations**.** Hinze and Wilson (1993) validated the importance of these techniques in safety performance.

### *3.3.3 Limitations of the Health and Safety Improvements Approaches*

Although the safety improvement approaches yielded positive results by reduced construction industry accidents with a drop of 22% in fatalities and 55% in days away from work during the period (1992-2005) in the USA, CPWR (2006). The industry suffered the loss of life of 16,068 averaging 1,147 lives per year for the same period, BLS (2009**).** This is an unacceptable number considering that it is the company's responsibility to insure the return home of their employee's safe and unharmed. The construction industry continues to lag only behind agriculture, mining and transportation industries, CPWR (2006)**.** This situation lead researchers to believe that progress reached a plateau and efforts to reduce accidents and improve occupational safety through the implementation of safety improvement approaches have stalled (Abdelhamid, 2003).

The main problem with the present safety improvement approaches is their failure to appreciate that any construction operation safety is determined before the time on which the equipment, procedures, and people are at the site. Improving safety performance is currently entrusted to rules, regulations, and devising new safer equipment only. This approach makes workers safety the responsibility of the contractor. However, owners play a significant role in pre-qualifying suitable and competent contractors with good safety records.

Architects and engineers can impact the construction project's safety through their design solutions. This is an area not fully utilized due to the lack of pursuit by the contractual, legal, or regulatory bodies (Behm, 2005).

The present legal agreements such as engineering-procurement-construction or design-bid-build do not outline the designer's responsibility to site safety as part of the design process. The long involvement of the architect and the designer in a construction project from inception to hand over gives them the ability to influence the project's outcome. They can identify and mitigate possible hazards more accurately than the contractor.

This fact led to the Prevention through Design initiative which addresses the health and safety requirements during the design stage in order to prevent or minimize potential hazards (Howard, 2008).

### *3.3.4 The Prevention through Design (PtD) concept*

Schulte et al. (2008) defined the PtD concept as “the practice of anticipating and designing out the potential safety and health risks and hazards which are associated with new structures, processes, tools, and equipment”. He also defined PtDas “organizing work to consider the maintenance, construction, decommissioning, and disposal/recycling of waste material alongside recognizing the associated business and social benefits”. The first concept of PtD was introduced by the International Labour Office (ILO) in 1985. It recognized the significance of the engineers and architects role in the construction projects safety during the design phase. This concept was supported later by The European Foundation for the Improvement of Living and Working Conditions. Jeffrey and Douglas (1994) concluded that there is a connection between safety performance of construction projects and design decisions which indicates that safety considerations should be part of the beginning of the design process. Szymberski (1997) states that the ideal time to incorporate construction safety is during the phases of conceptual and preliminary design. The construction phase safety approaches proved to be less effective than (PtD) which is introduced during the design phase.

Based on investigating two hundred cases of construction fatalities, Behm (2005) recommended design suggestions which can reduce fatalities as:

- Including of permanent lifeline attachments, anchorage points, and guardrail perimeter holes attachments during roof design.
- Including an early scheduling of permanent guardrail systems in the construction process.
- The specifying of scaffolding tie-off points into exterior walls for construction and maintenance purposes.

In order for the design specified concept of safety in construction to be effective, the contractor must closely follow this design and the related specifications (Behm, 2005).

The success of the (PtD) initiative does not depend on the input of the architect and engineers only. The contribution of business decision makers such as those who purchase services and products, manifested in insisting on specifications preventing and minimizing safety and health risks is also vital for the initiative (Schulte et al., 2008).

A number of countries are recognizing (PtD) as a cost-effective method to improve occupational health and safety. In 1994, it became mandatory in the United Kingdom for owners, contractors, and architects to include the health and safety aspects during the design phase.

Australia developed the National OHS Strategy 2002–2012, which specifies as a priority the eliminating of hazards at the design stages (Howard, 2008).

France passed regulations dictating an overall view of construction safety which includes the design phase. Similar regulations were adopted by other European countries (Behm, 2005).

## 3.4 Hazards associated with Steel Structure Construction

### *3.4.1 Design stage hazards*

Failure to incorporate safety principles during the design phase can result in unsafe site conditions and possible instability during construction while lifting, transporting, or handling of construction materials. Other considerations to be taken into account are safeguarding against progressive collapse and possible abnormal loads.

Figure (3.1) shows possible construction hazards together with their control and management (Industry Standard, 2009).

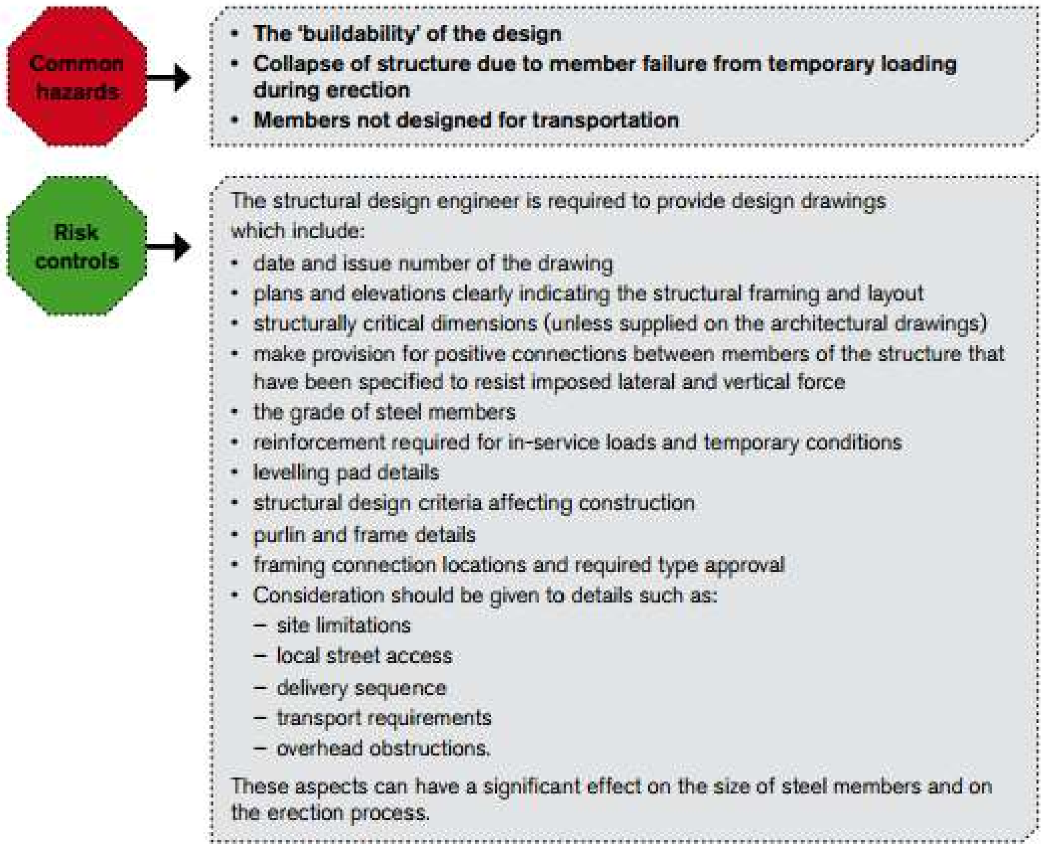



Figure (3.1): The Risks and Hazards during the design Stage (Industry Standard, 2009).

### *3.4.2 Fabrication stage hazards*

The task of insuring the perfect fit of members in a steel structure is the responsibility of the fabricator.

Figure (3.2) indicates the hazards and their management associated with the fabricator's work (Industry Standard, 2009).

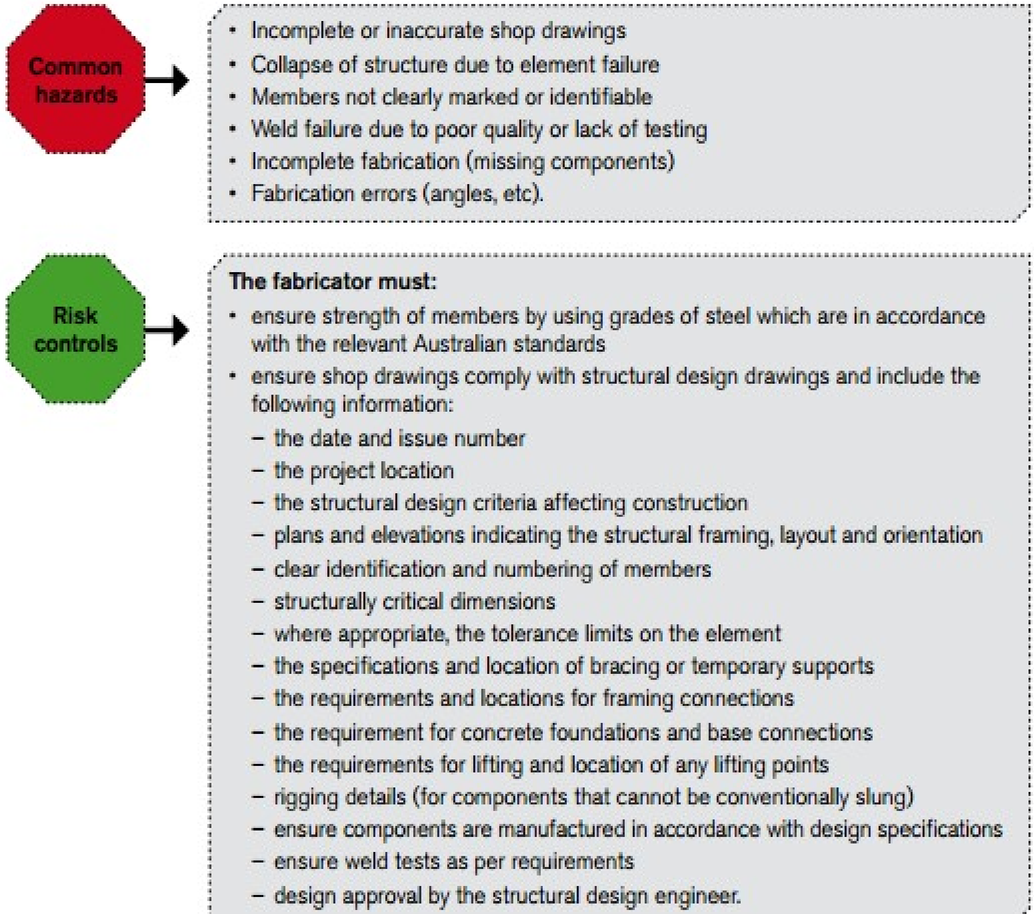



Figure (3.2): The Risks and Hazards during the fabrication Stage (Industry Standard, 2009).

### *3.4.3 Transportation stage hazards*

The transporter should plan the routes which he intends to use beforehand and obtain the necessary authorization and permits for wide or heavy loads, restricted routes, etc., Industry Standard (2009). Figure (3.3) states these hazards and their control.

**Common hazards** →

- Steel falling from slung loads while unloading
- Steel falling because the vehicle load is unstable or becomes unstable during unloading
- Vehicle becoming unstable
- Vehicle collapsing into a hole (if the site isn't adequately compacted)
- Lack of set-up space
- Lack of traffic management plan
- Access/egress: steep grade and short pitch
- Vehicle collision
- Worker falling from vehicle during loading and unloading.

**Risk controls** →

**Before loading vehicle**

The **Fabricator** should check that:

- the sequence of loading is agreed between the fabricator and the builder
- each member is clearly marked (together with its mass where it is over 1.5 tonnes) before loading.

The **Transporter** should check that:

- trucks have restraining spikes in place
- steel is supported and secured, so that there is no uncontrolled movement of the steel until it is ready to lift
- sufficient hardwood bearers, or equivalent, have been provided for loading.

The **Builder** should check that:

- the sequence of loading is agreed between the builder and the erector
- a crane of the required type and capacity is at the site
- the area for unloading is firm and level and checked for load capacity and where applicable or necessary, ground computations
- there is an adequate set-up area
- there is a traffic management plan
- the grade and pitch of access/egress is suitable and safe for the vehicles and their loads.

**When loading the vehicle**

The **Transporter** should check that:

- the vehicle and load is stable and load will remain stable during unloading.

**On vehicle's arrival at site**

The **Transporter** should check that:

- securing chains or straps are not removed until restraining spikes in place
- the steel has not shifted into a dangerous position
- the vehicle is positioned as directed by the erector and stabilised before the steel restraints are released
- if the unloading sequence can lead to the instability of loads, the steel is individually restrained and the loading configuration checked so that unloading does not result in the load or the vehicle becoming unstable
- the vehicle is not moved without the steel being properly secured.

The **Erector** should check that:

- loads are lifted in a level manner
- loads are not lifted vertically or at a slope
- loads are sufficiently secured to prevent inside lengths from falling out if the bundle is at an angle
- there is fall protection for workers and doggers on the truck.

Figure (3.3): The Risks and Hazards during the Transportation Stage (Industry Standard, 2009).

### *3.4.4 Erection stage hazards*

During the erecting stage, the strength and stability of both temporary and permanent structures should be insured. The erection engineer must provide erection procedures and guidance on structures' stability at each stage of the construction process. A Safe Work Method Statement (SWMS) similar to the one in Table (3.3) below should also be provided (Industry Standard, 2009).

Table (3.3): Erector tasks (Industry Standards, 2009).

**Safe Work Method Statement – Structural steel erection (sample)**

| What are the tasks involved? | What are the hazards and risks? | How will hazards and risks be controlled? (describe the control measures and how they will be used) |
|---|---|---|
| **3. Erecting stage** *(continued)* | • Unstable structure | • Builder or builder's representative and erection supervisor to inspect the frame to ensure it meets the erection engineer's specifications<br>• Check that bolts have been tensioned to specified torques. |
| **4. End of shift** | • Unsecured site | • Secure all plant and equipment<br>• Inspect site and clean up area. |

**Please ensure you have completed this SWMS correctly by checking the following.**

☑ **I have completed the form with the following information:**

☐ I have discussed with relevant employees, contractors and HSRs – what work will be high risk, the tasks involved, and associated hazards, risks and controls.

☐ I have listed, in the first column 'What are the tasks involved?' – the main stages for the tasks involved.

☐ I have listed, in the second column 'What are the hazards and risks?' – the hazards and risks for each work task under the relevant stage of construction.

☐ I have listed, in the third column 'How will the hazards and risks be controlled?' – control measures for the hazards and risks, based on the hierarchy of control levels 1 to 4 (listed below). I have chosen a control measure (and how it is to be used) that is as close to level 1 as is reasonably practicable.

**Control levels 1 to 4:**

1. **Eliminate risk** to health or safety associated with construction work.
2. **Reduce risk** to health or safety by any one or any combination of the following:
   - substituting a new activity, procedure, plant, process or substance
   - isolating people from the hazard, such as barricading, fencing or guardrailing, or
   - using engineering controls, such as mechanical or electrical devices.
3. **Use administrative controls,** such as changing the way the work is done.
4. **Provide appropriate personal protective equipment (PPE).**

☐ The crew has been inducted to this SWMS, and briefed to stop work immediately if the SWMS is not being followed.

The key risks involved in steel erection, and their controls are shown in figure (3.4):

**Risk controls** →

- considering perimeter screens, guardrails with integral toe-boards and wire mesh, debris nets, cantilever work platforms, scaffolding sheathed with protective material and/or lanyards to secure tools and equipment
- using materials boxes which are fully sheeted to enclose the load
- ensuring safety helmets are worn at all times.

**3 a) Before erection, to avoid collapse, the erector should:**

- ensure a sequential erection procedure is prepared, which has been approved by the erection engineer and is consistent with the marking plans
- ensure that an experienced steel erection supervisor is present at all times to oversee the implementation of the sequential erection procedure
- ensure an adequate exclusion zone to prevent risk to other people not involved in the erection
- only start the erection of a member or sub-assembly when equipment to ensure the structure's stability is available and being used
- ensure temporary guys or bracing are securely anchored
- place adequate visual barriers between guys and plant/vehicle movement areas.

**b) During erection, to avoid collapse, the erection supervisor must:**

- verify the stability of the structure in accordance with the erection engineer's specifications:
  - at the end of each work day
  - when fastenings may be incomplete
  - during strong winds or when strong winds are forecast
- seek approval from the builder (or erection engineer where appropriate) to cease work at unscheduled points where the structure has not been completed to the specifications of the erection engineer's design
- Obtain, from the builder, the erection engineer's written approval before loads are placed onto the structure
- where possible, start erection in a nominated braced bay (if this is not possible, make sure that the erection engineer is involved in developing an alternative site-specific sequential erection procedure)
- check the fittings for the support of columns during erection, to ensure adequate structural capacity for the erection conditions
- make sure that all beams are secured before releasing the slings
- make sure that all bolted connections are effective to ensure the stability of the steel structure.

**4 To avoid being struck by plant and before the use of a crane or any other powered mobile equipment, the erector should consider:**

- crane selection, access and siting in accordance with AS 2550 Parts 1, 4 and 5 (cranes, hoists and winches)
- protection of the public

Figure (3.4): Managing risk in steel erection (Industry Standards, 2009).


- the location of any excavations or underground services that may affect a crane load
- the proximity of overhead power lines
- the capacity of the ground or supporting surface to bear the load
- check the type and amount of packing required under the crane's outriggers to support the proposed loads
- written procedures for setting up and dismantling of the crane and the lifting method
- the composition of the rigging crew suits the job
- procedures for visual and audible signals between the crane operator and the erection crew
- ground support conditions
- selection of lifting gear
- emergency procedures
- prevailing or forecast weather conditions
- the need to avoid lifting loads over people.

The use, of two or more cranes to move and position loads, is hazardous and should be avoided if a single crane is capable of doing the job. Where it is necessary to use two cranes to «dual lift» members, the following controls are to be implemented:

- the weight of the load and its centre of gravity as well as the weight of the lifting gear must be carefully calculated.
- cranes of similar characteristics should be selected.
- the position of each crane should minimise movement and slewing.
- the lifting capacity of each crane must be 20% greater than the share of the load.

For further advice on multiple crane lifting, see *A Guide to Rigging*, chapter 18.

**5 a) Where plant is working near overhead lines, the erector should:**

- identify all powerlines services before permitting any crane or other mobile plant on site
- check that material and plant is moved or operated outside the "No Go Zone" of 3000 mm from an overhead electrical cable on a pole or 8000 mm if the electricity cable is on a tower line (If erecting scaffolding, the "No Go Zone" during this process is 4.6m distant and 5m below from the nearest power line)
- if work or plant is able to encroach on this clearance, the erector must obtain permission from the electricity company or develop a SWMS and work in accordance with it.

Note: Tiger battens do not protect from risk of electrocution or electric shock. They provide a visual warning only.

**b) When plant is working near underground services, the erector should:**

- ensure that, unless permission has been obtained from the utility company, work is not carried out closer to the services than:
  - 3 metres in the case of an underground asset registered under the Pipelines Act or an electricity cable with an in-service voltage greater than 66 kV, or
  - in the case of other services, 500 mm for plant and equipment and 300 mm for individuals.

Figure (3.4) Cont.: Managing risk in steel erection. (Industry Standards, 2009).

### 3.5 Accidents in Steel Structure Construction

The Occupational Safety and Health Administration (OSHA) investigated ninety-six structural collapses which took place during construction and involved fatalities and injuries, Ayub (2010). Sixty of these incidents were related to the collapse of temporary or permanent steel structures. Construction projects should be executed according to the relevant codes and standards in a manner that ensures their integrity and capability to withstand all natural or manmade elements for the long period of their designed time. Buildings should not be safe only once finished but should also be safe during the period of their construction. It is misleading to assume that a building can sustain construction loads being less than its design loads. The construction process and construction loads should be carefully reviewed to ensure the safety of the construction crew.

The uncertainty of a structure's stability is a major concern during construction. A collapse during construction can be due to an error in the process or to an unforeseen load being loaded to an unfinished steel frame. Contractors and engineers draw from their past experience to predict some of these uncertainties and provide mitigating solutions.

The hazards to which construction workers are exposed have wide and different ranges also workers as bystander encounter hazards caused by others working nearby them. (Ayub, 2010).

Heng (2006) showed that the following major factors are those leading to work accidents

i) Inherited or acquired social environment behaviors can result in negative attitudes leading to unsafe manners.
ii) Unsafe acts committed by people
iii) Falling or being hit by moving objects.

Accidents are caused and do not happen and their major causes are unsafe conditions and unsafe acts. (Heng, 2006).

- An unsafe condition: can either be physical e.g. defective tools, or environmental e.g. contaminations, Frederick (2002). These conditions require continuous monitoring due to their changing nature with the progress of work on site, (Cotton, 1995).
- An unsafe act: are actions caused by the people on the job site which should have been done differently or not done at all, (Heng, 2006).

Furthermore, If the worker does not inform others about an unsafe condition, then he or she is committing a neglecting act, (Clark, 2000).

The cause of most accidents is a combination of an unsafe condition and an unsafe act (Kennedy, 1997).

Table (3.4) relates each construction occupation with a corresponding possible accident/hazard type (Eckenfelder, 1997).

Table (3.4): possible accidents/hazard types (Eckenfelder, 1997).

| Occupation | Possible Accident/Hazard |
|---|---|
| Brick masons | Cement dermatitis, awkward postures, heavy loads |
| Stonemasons | Cement dermatitis, awkward postures, heavy loads |
| Hard tile setters | Vapor from bonding agents, dermatitis, awkward postures |
| Carpenters | Wood dust, heavy loads, repetitive motion |
| Drywall installers | Plaster dust, walking on stilts, heavy loads, awkward postures |
| Electricians | Heavy metals in solder fumes, awkward posture, heavy loads |
| Electrical power installers and repairers | Heavy metals in solder fumes, heavy loads |
| Painters | Solvent vapours, toxic metals in pigments, paint additives |
| Plasterers | Dermatitis, awkward postures |
| Plumbers | Lead fumes and particles, welding fumes |
| Pipefitters | Lead fumes and particles, welding fumes |
| Steamfitters | Welding fumes |
| Carpet layers | Knee trauma, awkward postures, glue and glue vapour |
| Soft tile installers | Bonding agents |
| Concrete and terrazzo finishers | Awkward postures |

| | |
|---|---|
| Glazer | Awkward postures |
| Insulation workers | Synthetic fibers, awkward postures |
| Paving, surfacing and tamping equipment operators | Asphalt emissions, gasoline and diesel engine exhaust, heat |
| Roofers | Roofing tar, heat, working at heights |
| Sheet metal duct installers | Awkward postures, heavy loads, noise |
| Structural metal installers | Awkward postures, heavy loads, working at heights |
| Welders | Welding emissions |
| Soldiers | Metal fumes, lead, cadmium |
| Drillers, earth, rock | Silica dust, whole-body vibration, noise |
| Air hammer operators | Noise, whole-body vibration, silica dust |
| Pile driving operators | Noise, whole-body vibration |
| Hoist and winch operators | Noise, lubricating oil |
| Crane and tower operators | Stress, isolation |
| Excavating and loading machine operators | Silica dust, histoplasmosis, whole-body vibration, heat stress, noise |
| Grader, dozer and scraper operators | Silica dust, whole-body vibration, heat noise |
| Highway and street construction workers | Asphalt emissions, heat, and diesel engine exhaust, heat |
| Truck and tractor equipment operators | Whole-body vibration, diesel engine exhaust |
| Demolition workers | Asbestos, lead, dust, and noise |
| Hazardous waste workers | Heat, Stress |

## 3.5 Usage of Visualization to Improve Construction's Health and Safety

The design phase of a construction project is responsible for work accidents as much as the construction phase. The available methods to conduct risk analysis and evaluate associated hazards of different design options are limited. The Building Information Modelling (BIM), provides visualization tools which help designers identify potential accidents and conduct safety planning before construction (Kasirossafar and Shahbodaghlou, 2013).

Documenting the sequence of as-built construction operations by integrating time-lapse movies with virtual reality models is not deeply investigated however individual applications in various areas are reported:

i) Video Sequences

In construction education Kramer, Sankar and Hingorani (1995) evaluated the use of a picture phone as a two-way communication medium between a site instructor and trainees in a classroom. Practical problems were discussed by showing still site images. The system proved to be effective apart from the limitation associated with still images that does not adequately represent fast moving operations.

Fischinger, Cerovsek and Turk (1998) and Turk (2001) presented a web based application related to earthquake engineering which includes a pictorial images database of earthquake damaged structures provided with textual descriptions. Such system demonstrates the value of images as an archive however; its focus is on the structures and not the construction operations.

Fischinger et al. (1998) and Martini (1999) developed a teaching tool with the objective of understanding a structure through visual analysis and interpreting visual phenomena by applying the theories of structural principles to images of completed or uncompleted structures. This tool suffered from the limitations associated with still images

Saad and Hancher, (1998) developed a multimedia system composed of audio, graphics, video, and text files called the "Project Navigator" to track and document the progress of a construction project. The video files captured by a camcorder were digitized, and edited to improve their quality. The difficulty of this system is the extensive human effort associated with analysing the image sequence of long durations.

Miah et al. (1998**)** described the use of video sequences utilizing a mobile video camera within a construction setting. The system uses wireless transmission to relay the construction site's digital images to a remote destination thus transmitting progress information to relevant parties without regular site access.

Nuntasunti and Bernold (2002) presented a website at the project's site that provides continuous access in order to assist in the activities of planning and control the system includes a computer with internet access, a motion detector, and a video camera; thus, facilitating project's progress real-time recording and review. The motion detector can also act as a tool for surveillance. The site-web-site applies the time-lapse concept by capturing and storing images at a frame rate.

ii) Virtual Reality Applications

Education was the first field in which virtual reality was applied. Shelbourn et al. (2001) developed a multimedia tool using virtual reality technologies in a laboratory setting for the purpose of teaching integrated systems.

Sampaio et al. (2005) developed a prototype system which allows a visual simulation of the progress of a structure in order to assist students in understanding construction activities.

Ganah and Bouchlaghem (2005) found that visualization tools including rendered virtual reality models, video animation, and images were not used by the industry. The authors used virtual reality to construct a system which conveys visually the design information to various teams on site.

Shelbourn et al. (2001) employed virtual reality to develop a system used in diagnosing building defects. Site visits' exercise to defective buildings are associated with logistic difficulties and this system brings site experiences to students in their classrooms.

Mckinney and Fischer (1998), Chau et al. (2004), Fischer and Kunz (2004), and Chau et al. (2005) devised applications incorporating the time dimension to further extend beyond the design phase the use of 3D CAD which resulted in allowing planners to prepare better accurate schedules.

Kamat and Martinez (2001), Whyte (2003), and Wokesepp and Olofsson, (2006) gave some reviews of 4D visualization applications which link schedule information with 3D design data thus generating animations of the construction operations.

Wang et al. (2004) and Chau et al. (2004) further extended these applications to cover quantities estimations and cost evaluation.

All the above applications do not capture the as–built process due to the fact that they are based on a 'planned' sequence, which does not correspond to the 'actual sequence'.

Kim and Kano (2008) proposed a method comparing virtual reality with photographic images in order to highlight the differences between the planned virtual reality model and the actual situation at the job site.

### 3.6 Usage of Animation for Health and Safety

The poor management of the Health and safety issues by companies resulting in insufficient staff training is the main cause of the high accidents rate in the construction industry. An efficient and credible visual training program can reduce accidents and save lives bearing in mind that 80% of the human memory skills are obtained visually. There are several visual tools that can be utilized in such a program amongst them are dramas and animations. Adopting the visual tools approach relieves the training program from the boring theoretical nature and makes it more attractive and enjoyable. This approach can present real construction accidents and demonstrate the mistakes that led to them and the preventive measures that should have been followed. Dramas and animations have a higher appeal with the low educated level of construction workers who finds it rather difficult to understand theoretical training given in workshops (Arsalan and Kivrak, 2014).

#### *3.6.1 Health and Safety Trainings Using Dramas and Animations*

The training exercise by dramas and animation is used to present work place accidents demonstrating what went wrong and how to avoid it.

The first part of the exercise is the data collection of previously recorded accidents regarding their causes, numbers, and frequency. Statistical data published by governments, professional institutes, and nongovernmental organizations are available and can serve as basis for this exercise. The data is then grouped under several headings such as their frequency or their severity (Arsalan and Kivrak, 2014).

In the second part accidents scenarios are prepared where construction accidents are defined in terms of causes, frequency, places …etc. These scenarios should also address precautionary and preventive measures which should be taken.

The following part is the designing of the drama and animation in which an innovative effort is needed to create the material which is presented in different levels of importance and for various types of works. This approach will help in preparing specific different training dramas for each work category. Computer animations constituted from images and musical rhythms without a spoken language can serve an international audience (Arsalan and Kivrak, 2014).

The last part is the applications of the dramas in the health and safety training programs and having their impact and results evaluated by the relevant health and safety departments in construction companies. A further advantage of this approach is the ability to create a specific accident scenario and preventive measure for a specific job activity and give the visual training on site before carrying the activity by the workforce.

## 3.7 Time-Lapse Videos

Time-lapse photography is a well-known and established method used in recording the progress of construction activities. Rather than continuous filming which could prove to be expensive and logistically difficult, short interval photographs or videos with a fixed time span and duration are combined to create a movie representing the actual series of events. This method can be used as (Abeid and Arditi, 2002)

- Recording purposes e.g. weather, work progress, consumed materials …etc.
- Management tool to evaluate performance for the purpose of control or improvement.
- Planning base for similar future activities.
- Marketing tool to possible clients or in exhibitions through the demonstration of working capabilities.
- Training of staff.

### *3.7.1 Equipment and Movie making*

The animations and compilation of time laps images need to be converted into a movie in order to achieve its objectives. It is possible to resort to a professional commercial solution which is more suitable to bigger projects; however affordable means in the form of laptops and digital cameras can give satisfactory results at much lower costs. The movie creation process goes through the following steps:

1-Image capturing: The starting activity in movies creation is the filming by still pictures or short videos at regular intervals throughout the duration of the monitored construction activity. The camera should be fixed at the same position and arrangements to connect to a power source or recharge facilities and surge protection should be provided. The number of images or videos can be determined by deciding on the length of the movie bearing in mind that a continuous movie requires 25-30 frames per second, which represents the setting interval between images, hence a five-minute movie will require 7500-9000 frames. Image intervals can be controlled either by cameras equipped with the necessary software or by a PC connected to the camera. The images can then be stored on the camera or PC however those stored on the PC provide a better solution for future activities. It is advisable to create a backup copy of images or videos.

2-Camera location: Some of the important principles in choosing a site camera location is that it should not interfere with works, in a protected zone from unauthorized access and weather, and positioned so as to have a clear and comprehensive view of the monitored activity.

3-Time lapsing: Work activities are usually recorded on selected and not real-time intervals. This implies a frame rate less than the acknowledged 25-30 frames per second. A 10-hour movie captured at 1 frame per second can be viewed in 20 minutes. Such movies are not suitable for control purposes or to evaluate workers' productivity however they are ideal for documenting and monitoring actual work in progress. It is worth noting that the acquired images interpretation is done by human observation and hence prone to errors. The way to avoid this is to automate the interpretation process to obtain unbiased automatically extracted information from images.

The question of the optimum frame rate becomes important in order that no step is completely missed by falling within the capturing intervals which was the subject of several studies.

Abeid and Arditi (2002) described the basics of time-lapse digital photography.

Everett et al. (1998) emphasized the monitoring capability of time-lapse in construction operations rather than its use as a productivity measuring tool. They highlighted the benefits of this approach in documentation, claim resolutions, workers and public education, and fund raising.

Everett et al. (1998) concluded that an interval frame rate of 1fps to 1fp5s is most common and sufficient for monitoring construction activities.

Abeid and Arditi (2002) recommend a recording rate of 60fpm (frames per minute equivalent to 1fps). They recognize that various operations require differing details which are translated into corresponding frame rates however they fail to specify optimum frame rates required for each operation.

Kang and Choi (2005) analysed the errors resulting from time-lapse movies which use different frame rates. They assigned a 70% confidence level to rate of 1 frame per minute for the purpose of monitoring construction operations.

The advantage of using time-lapse videos in controlling the time required to view a movie are very clear however the risk associated with human observations errors still remains.

## 3.8 Accidents Investigation

In order to use site accidents reporting as a knowledge management tool, the reported accidents need to be investigated to establish their cause and required prevention actions. Accidents Investigations are conducted by trying to find the answers to the following questions:

1) What is the nature of the accident and whether it should be investigated?

When the accident's cause is determined, it is found that it did not relate to chance but was predictable and hence prevented. The investigation should concentrate on facts leading to preventive actions. An accident should be investigated in order to find its cause, fulfill legal requirements, establish the cost impact and associated compensation claims, and to check whether safety regulations were adhered to (CCOHS, 2006).

2) Which party should conduct the accident's investigating?

The investigation team should be experienced and knowledgeable of work environment, procedures, and process and is composed of labor and management representatives.

3) What are the investigation steps?

The accident investigation process steps are: (CCOHS, 2006)

- Report the accident to the relevant party or person.
- Identify the accidents root causes
- Develop and report a plan for corrective action
- Make the required changes to facilitate the implementation of the plan.

4)Determining the cause of an accident?

Accident models such as Heinrich's domino theory or the sophisticated Management Oversight and Risk Tree can be used.

The model shown in Figure (3.8) specifies five categories for accidents causes namely task, material, environment, personnel, and management.

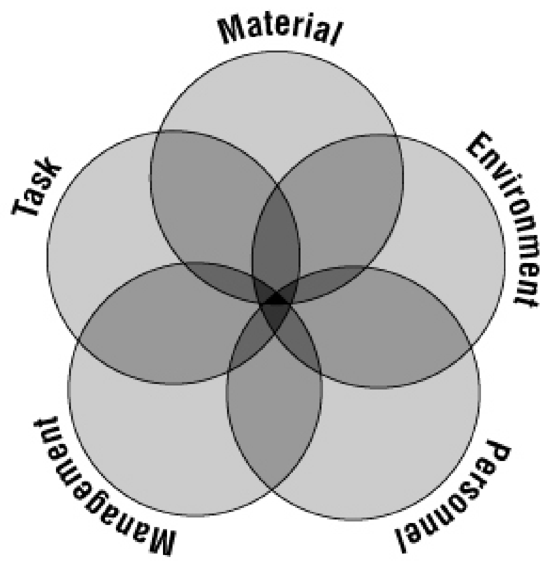



Figure (3.5): Accident causation (CCOHS, 2006).

- Task

The work procedure is examined to check If a procedure for safe work was used

- Any change in conditions resulting in the procedure becoming not safe?

- Were the proper materials and tools used?

  Were the safety devices in place working properly?

- Material

Causes related to equipment and materials are determined by questioning:

- Did an equipment fail?
- What was the cause of failure?
- Was the cause related to design?
- Was the material not to design and specification standard below the specified standard?
- Should personal protective equipment (PPE) be used?
- Were these PPE actually used?
- Were the users of these PPE trained properly?

Once the answer shows a condition which is not safe, the investigator should ask why the situation was allowed to happen.

- Environment

The environmental conditions at the time of accident should be identified especially if there is a sudden change from the usual and normal conditions. The answers to the following questions help determining the environmental effect: (CCOHS, 2006)

- What were the weather conditions and were they too hot or cold?
- Did excessive noise levels affected workers' attention?
- Was the site provided with adequate light?

- Did dust, gases, or toxic fumes exist?

- Personnel

The investigation should pay consideration to the condition of the individuals involved in an accident. Answers to the following question help shed light on the personal conditions of the workers: Were workers trained and have adequate experience in their work? Were workers physically fit, healthy, not tired or stressed when conducting their job?

- Management

- The Management systems have direct impact on accidents and management is legally responsible for the safety of workers and workplace. The role of management can be evaluated by examining the following: were safety rules and procedures clearly written, communicated to the work force, and properly enforced? Were workers adequately trained and supervised?

- Had similar hazards been identified, analysed, and conditions leading to them eliminated?

- Was regular maintenance and inspection of equipment carried out according to their operating and safety manuals?

5) How are the facts collected?

-The accident investigators gather information from injured workers(s)

-The investigation with workers should start only after rescue and medical treatment activities are completed. The site should be examined for any physical evidence as soon as legally possible as such evidence can suffer change or obliteration.

- Eyewitness Accounts

- Witnesses should be interviewed while their memory of the accident is still fresh. They must be kept apart and interviewed alone at the site of the accident if possible.

-Background Information: An important source of information may be found in the work documents such as design manuals, maintenance reports, safety reports, training reports, and other such records.

6) The analysis, conclusions and recommendations

When the facts regarding, the accident are collected and in order to prevent the same accident from happening again, an analysis is conducted to understand why the accident took place. The analysis should be supported by direct evidence or eyewitnesses and not on assumptions.

Recommendations are drawn which should be specific and constructive identifying the root causes and factors contributing to the accident.

An accident report is completed setting out the following:

- The primary causes and contributing factors to the accident.
- Identification of the unsafe conditions.
- A check list of action steps to eliminate the accident from reoccurring.

### 3.9 Summary

Construction site health and safety is a very wide subject involving several parties, activities, and approaches. It is therefore imperative to identify a special area of interest and a specific target to be achieved within this area. As the time and resources available for this research project are finite, the work done reviewed this wide subject in order to focus on an activity of high importance and recognize a tool which can impact improvement in its safety approach.

The steel structure construction activity was selected due to the high risks associated with it. From within the several sub activities included in the steel structure construction, the subject of steel structure erection was selected due to its suitability to modelling.

The second objective was to select a suitable and effective training method. Visual tools were seen to render better results especially with an illiterate workforce. Furthermore, the training becomes more efficient when it is tied to the daily tasks just before their execution. Hence training videos and other material were designed to coordinate with the work to be performed and preferably as morning sessions.

The subjects of image recognition required for the coordination with the work force daily tasks shall be addressed in Chapter 6 in conjunction with the system's development.

Safety reporting and the storage and output of relevant safety reports which are the core of a project knowledge management system were studied. The subject of accident's investigation was also reviewed being a part of the knowledge management system and could be incorporated within the envisaged reporting activity.

# Chapter 4- Research Methodology

## 4.1 Introduction

The research methodology covers the reasoning and the philosophical suppositions that highlight the particular study, Dainty (2008). The choice of research strategy significantly effects the requirements of the research methods that are used for examining a problem and establish the structure for collecting, interpreting, and analysing data. An essential requirement for the development of computer integrated solution to any given problem is that the development should follow a proven and established process. Such a process brings predictability and discipline to the development. Any such process consists of consecutive stages which must be covered. An effective series by which an effective research methodology can be designed was presented by Sanders et al. (2007). The relevant questions that arise in this respect are of the sort: What are the most fitting criteria for choosing the research methodology? How can the strength of the research be assessed? What are the current tendencies (Panas and Pantouvakis, 2010).

The determination of a suitable research methodology is based on answering four main questions (Crotty, 1998).

- What theory of knowledge rooted in the theoretical point of view defines the research? (Research philosophy)
- What theoretical viewpoint is behind the methodology in question? (Research approach)
- What strategy oversees the selection of methods and links it to results (e.g. survey, experimental...etc.)? (Research strategy)
- What planned actions are to be used (interviews, questionnaire...etc.)? (Research choices)

These questions symbolize definite interrelated stages of decision making inside the research design process.

The three fundamentals of inquiry which are knowledge claims, strategies, and methods are joined to form various methodologies to research which in turn are translated into processes as shown in Figure (4.1). (Creswell, 2003).

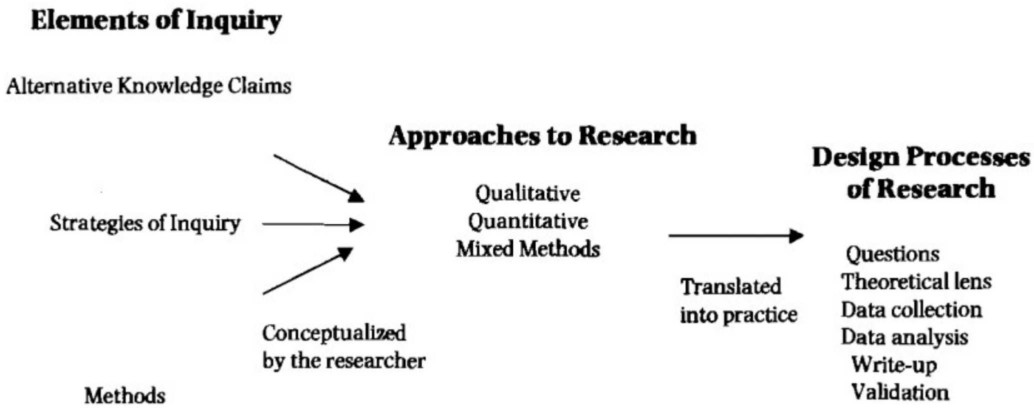



Figure (4.1): Elements of inquiry leading to methodologies and design process (Creswell (2003).

This chapter addresses these four questions and provides their answers related to the project which is the subject of this research work.

## 4.2 Research Philosophy

The research philosophy provides the validation for the research methodology which in turn is learned from the nature of the addressed research problem. Different research philosophies can differ on the aims and the steps taken to achieve them but are not necessarily at odds and the choice remains defined by the knowledge being investigated in any particular research project, May (2011). Two main frameworks can define research process which are positivism and constructionism. The first assumes that the reality is independent from the problem being investigated while the later suggests that the interpreted meaning is created by participants, Ostlund et al. (2011). The type research problem being investigated in this research project is seemed to fall under the second framework of constructionism. The classification of site safety hazards according to frequency and importance and the most suitable methods of mitigating them is a subjective matter. This project tends to rely on information and data gathered from the published literature of relevant, reliable, and informed sources and data generated through the undertaken research work by surveys and feedback on presentations.

## 4.3 Research approaches

The chosen research approach can be quantitative, qualitative, or mixed. The quantitative, approach uses the affirmative assertions for knowledge developments. It uses strategies such as surveys, experiments, and collects data in a proven scientific form, Fellows and Liu (2003). The experiments are true experiments with random allocation of treatment subjects' conditions, non-random designs, and single subject design, Keppel (1991). The surveys are based on data collection from interviews as well as questionnaires aiming at the purpose of arriving at generalized conclusions derived from a sample of population, Babbie (1990). The consecutive steps carried out in a quantitative research approach vary according to the specific research topic however a typical flow of work can be defined as follows, (Bryman and Bell, 2003).

- Literature review to establish the phenomena or theory to be investigated.
- Identification of research design.
- Identification of subjects e.g. respondents to questionnaires or participants in interviews.
- Development of appropriate questions for the research subjects.
- Data collection and analysis.
- Development of the conceptual model
- Development of the computerised model
- Write up of findings and conclusions.

For several years, the scientific approach with an emphasis on quantitative studies has been rising resulting in a fact that research in disciplines like engineering and management of technology has been pushed towards adoption of quantitative scientific method. However, a rising appreciation of the value and suitability of qualitative studies has surfaced recently. This is due to the recognition of their potential for such methodologies to get to the bottom of the symptoms of quantitative studies issues and problems and facilitate the understanding and awareness of basic behaviours and principles, (Fellows and Liu, 2008).

Tesch (1991) identified three approaches to the qualitative analysis of data:

- Language based – focuses on the use and meaning of language with the target of reading between the lines.

- Descriptive based – attempts to develop a rational and thorough view of the issue from the perception of respondents and participants.
- Theory building – seeks to build a theory out of the study's collected data.

The above approaches admit that meaning is settled between people, created socially, and modified over time. Therefore, it is essential to observe of social relations in the theory development.

Oakley (1994) suggests that 'qualitative' describes the research which comes out from the participants' opinions.

Conducting a qualitative research usually follows general identified steps which need not be followed linearly or all included. However, these steps help to establish a framework and organize the research approach, (Sauro, 2013).

- Determine focused research questions.
- Design the study and collect input data from users establishing who will participate, when is the data collected, where is the data collection location, and what equipment or facilities are needed
- Analyse the data as an inconspicuous observer and generating a coding system to cater of the large amount of data associated with this approach.
- Generate findings by integrating the numerous collected amounts of recordings, videos, and notes.
- Validate findings by using other methods such as surveys.
- Report results by starting with findings.

An alternative approach to the quantitative or qualitative strategies is the one that entails gathering and studying the two types of data in one study. The idea of mixing the different methods was introduced by Campbell and Fiske (1959). They persuaded other researchers to adopt their method to study several lines to data collection in a study. These incited others to mix available methods and interviews and observations were combined with surveys (Sieber, 1973).

Due to the facts that limitations are found in all the methods, researchers believed that the prejudice inbuilt in a method could cancel or counteract the prejudice of other methods (Jick, 1979).

In a mixed method approach the researcher bases knowledge claims on realistic grounds. It employs strategies that engage collecting data sequentially or simultaneously to comprehend research problems. The data collection includes collecting numbers information and text information resulting in the final database representing both quantitative and qualitative information.

The mixed method approach steps can be summarised as: (Creswell, 2003)

- Broad survey to generalize the result to a population.
- Focus on open ended interviews with participants.
- Select sequential qualitative and quantitative data.
- Conduct statistical and text data analysis.

Choosing a research strategy is governed by its suitability to the undertaken research subject. The strategy should be the one that can best answer the question being raised. The strengths and weaknesses of each strategy can be summarised in table (4.1) (Johnson and Onwuegbuzie, 2004).

Table: (4.1) Research strategies strengths and weaknesses (Johnson and Onwuegbuzie, 2004).

| Strategy | Strength | Weakness |
|---|---|---|
| Quantitative | - Can be generalized and repeated on different populations.<br>- Cannot be influenced and is independent from researcher. | - Does not reflect population's views and understanding.<br>- Not particular to a specific context. |
| Qualitative | - Can provide deep study of limited cases.<br>- Describes complex phenomena<br>- Describes dynamic processes.<br>- Facilitates understanding of the concept. | - Findings are difficult to be generalized.<br>- Data collection is difficult and time consuming.<br>- Results can be influenced by the researcher. |

| | | |
|---|---|---|
| Mixed | - Combines the benefits of both strategies. | - Difficulty in qualitative evaluation of quantitative data<br>- More expensive and time consuming. |

#### *4.3.1 The adopted research approach*

The objective of this project is to develop a computerized project management system incorporating site health and safety concerns based on obtained visual data. This objective was achieved by:

1. Reviewing previous research addressing the issues regarding safety in construction.
2. Developing a computerized model which incorporates real time work progress imaging together with the applicable of site safety standards, codes, and requirements.
3. Develop or adapt existing suitable and specialized computer software to perform the image recognition activity.

The adopted approach in realizing the project's objectives was based on the following:

1. Using photographic data and image recognition analysis techniques in the steel construction safety field.
2. Building a four-dimensional model incorporating the three-dimensional image data available from an actual project, indexing all real images taken, searching and retrieving selected time images and comparing them with the rendered project design model.
3. Foresee future activities on site by utilizing the project work program and identifying the associated site risks and hazards.
4. Identify safety problems and danger of injuries associated with a specific daily job within a construction projects.
5. Automatic output of relevant safety reports.
6. Display the safety reports via an advanced visualization tool.

The linkage between different research stages can be explained in figure (4.2) below.

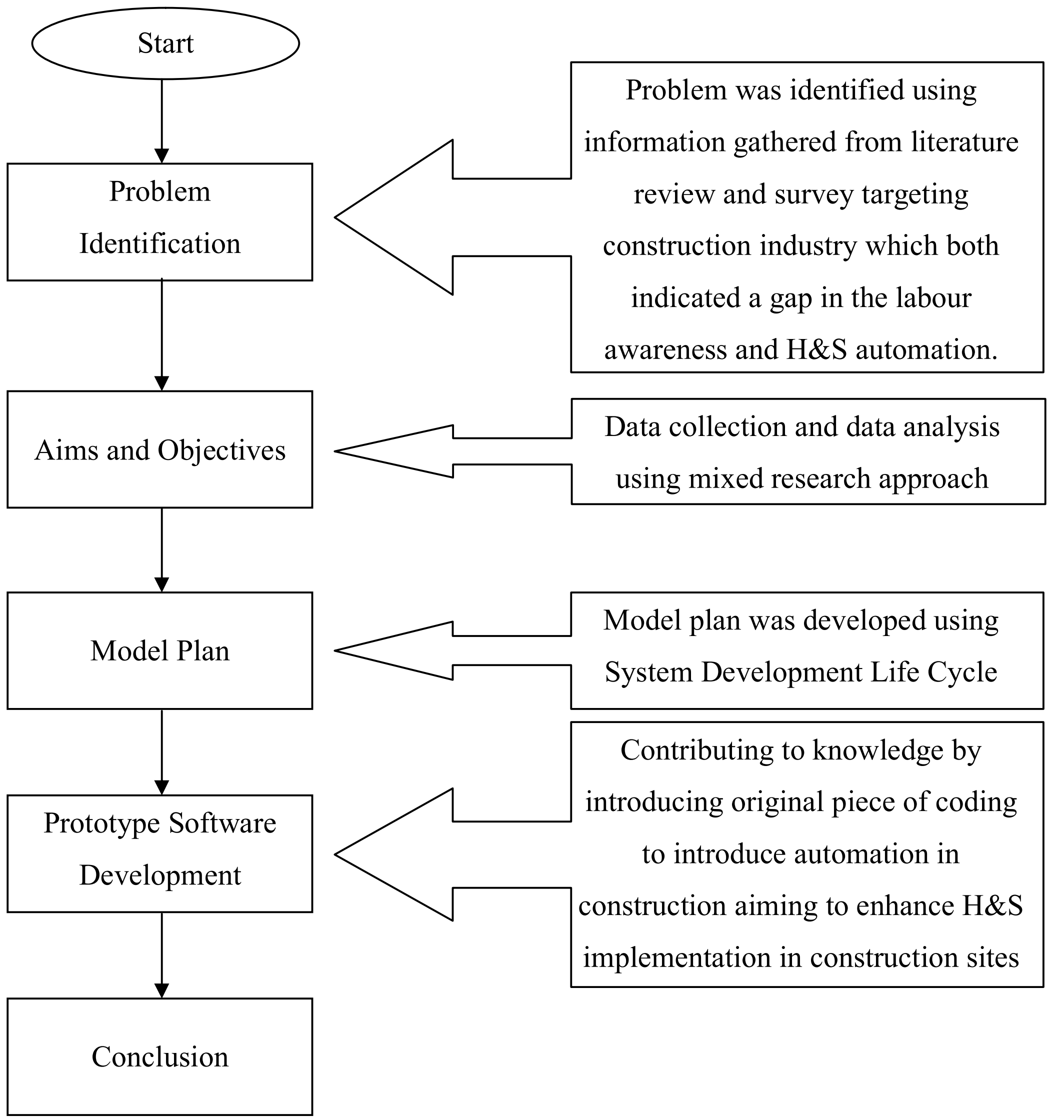



Figure (4.2) Research process steps flowchart.

## 4.4 Research strategy

The research strategy is how the researcher envisages carrying out the project, Saunders et al. (2007). The construction site safety and management system being developed in this project is related to the identification of site hazards together with the required precautionary measures in order mitigate these hazards. The system uses photographic data and image recognition analysis techniques to analyse the set of input data which is in the form of digital photographs in order to identify a specific work activity. The system then generates a four-dimensional model incorporating the three-dimensional image data available from an actual project, indexing all real images taken, searching and retrieving selected time images and comparing them with the rendered project design model. By utilizing the project work program, the model sets to identify the associated risks and hazards and outputs the relevant safety training method together with the relevant safety report. The computerized model development went through three main stages:

- First stage: Literature review and identification of model requirements.
- Second stage: Conceptual model development, data collection, and data analysis.
- Third stage: Implementation, validation, and output of results.

### *4.4.1 First stage*

a) Literature review

The literature review was concentrated on the subjects addressed by the research objectives the first of which was related to subjects dealing with health and safety in construction in general and in steel construction in particular.

The review was then focused on computerization in construction which included:

- 3D and 4D model applications.
- Computer programs applications.
- The building information model.
- Information management applications.

A further review was undertaken to capture the information related to image processing and recognition in general. The review concentrated on the specific image recognition literature related to the construction activity both in a documenting or interactive role. As the health and safety issue is an important part of the research, special attention was given to literature dealing with image recognition applications related to this subject.

The literature review was a continuous process throughout the course of the project. The conducted survey outlined the need an importance of construction site safety training. It also emphasised the priority of developing techniques other than the adopted briefings and pamphlets. This need was then reflected in pursuing to include visual training animations, and the related literature on their applications was surveyed in order to include them in the developed computerized model.

b) Identification of model's requirements

The first step in generating a model is the definition of the function it is supposed to serve and defining its requirements (Miles and Hamilton, 2006).

The flow chart shown in figure (4.3) outlines the model requirements and their interactions.

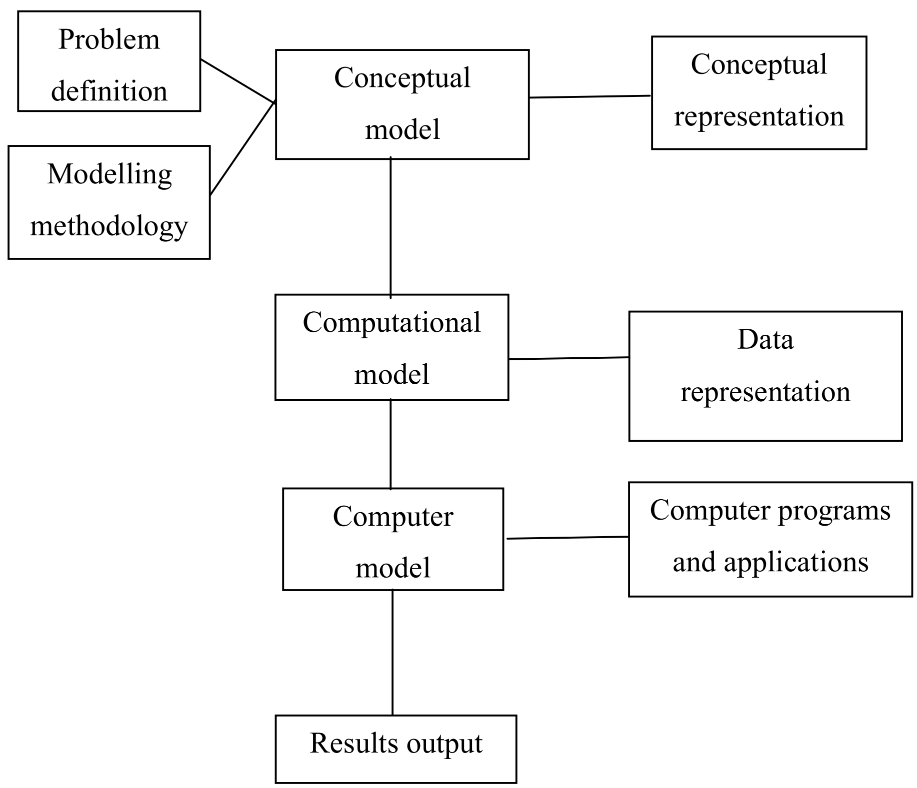



Figure (4.3): Project model requirements

### *4.4.2 Second stage*

a) Conceptual model development

The main objective of conceptual modelling is the extraction of a high-quality abstract plan of information or software system, Chen et al. (1999), Olive (2007) and

Thalheim (2000). This understanding deliberates on the outcome of conceptual modelling and obstructs the generation of a conceptual modelling general theory. Modelling is built on well understood sophisticated languages like the ER modelling language or might be fuzzy like the UML, Chen et al. (1999). Conceptual modelling is constructed on the basis of modelling forms only and has three fundamental dimensions: (Thalheim, 2010)

1. Modeling language forms are used during conceptual modeling and their syntactics, semantics and pragmatics must be well understood.
2. Application domain collection serves the understanding of the problems intended to be solved, the chance of solutions for a given system, and the stipulated requisites and architecture for the chosen solution.
3. Engineering is leaning in the direction of inclusion of design problems with experiences trimmed down to a controllable scale.

The first dimension is handled and well understood in the literature. The second dimension has little understood support, Bjorner (2009). The third dimension received considerable attention by data modellers but not into research (Simsion, 2007).

A suitable platform is designed to input the provided digital photo data and the input data is then enhanced by a data preparation method. The 4D model incorporating the 3D CAD design with the time schedule of the projects generated and then imported to the data input platform. Selected activities are detected within a chosen image and the relevant reports and videos are outputted. In order to develop the conceptual model, it is required to specify its function, Miles and Hamilton (2006). The performed function is illustrated in figure (4.4):

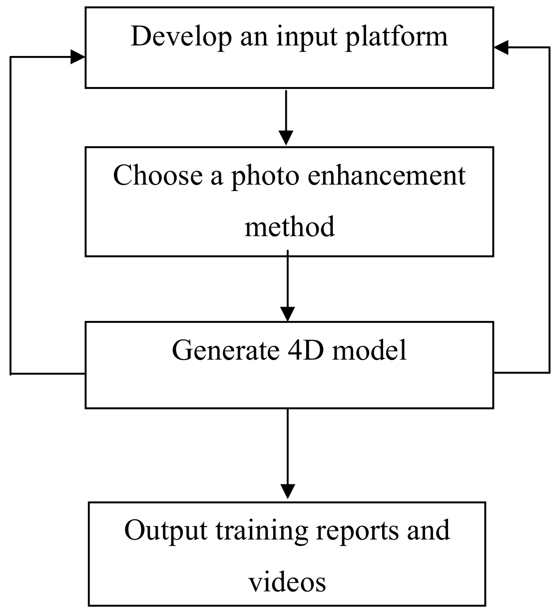



Figure (4.4): Conceptual model case view

b) Survey data collection

The nature of the problem in any field of construction management implies a suitable research approach, Wing et al. (1998). The choice of the approach should be based on the fact that it will likely result in practical and pragmatic solutions. It is also important to determine whether the emphases are on in-depth knowledge or wider participation.

Surveys can take the form of postal, electronic or telephone communications with the important issue being which means shall result in the optimal response rate, Root and Blismas (2003). The selected method in this project was an electronic questionnaire survey served by emails. This choice was dictated by the fact that respondents were numerous and dispersed however it faced related limitations. The limitations were generally attributed to the inability to ensure the respondents understanding of the questionnaire's contents and inherent lack of depth in the raised questions due to the fact they are meant for a wide range of audience.

The available literature suggests several actions and recommendations to improve the response rate. Closed end questions and a comprehensive cover letter were sighted by Root and Blismas (2003). While Whelan (2007) indicated that expressing replies' anonymity encourages some reluctant participants to take part in the survey.

The dedicated survey chapter and the survey appendix reflect in more details on this subject.

c) Survey objectives

A survey was carried out to explore the use of construction site digital cameras in existing construction sites. Another target of the survey was to collect information on the health and safety briefings and training given and their relation to the planned daily construction activity.

The survey objectives were related to two main areas:

- Identification of respondents' qualifications and job titles. This information is very important in analyzing their response to specific questions as it reflects their involvement and concern regarding the question's subject.
- Digital photos acquisition facilities at construction sites and the purpose of their use in the various site construction activities.
- Labor awareness of the hazards associated with their specific day activities.

The frequency and purpose of reviewing site photos was investigated to determine whether their output is put into proper use. The second objective of the project related to construction site's safety was also included in the survey. The awareness and training related to site health and safety issues was included as a part of the survey. The obtained survey output information is intended to assist in the evaluation and the practicality of the model section related to the image processing, reports output, and training videos parts within the overall modelling process.

d) Sampling method

A wide variety of methods is used by researchers for information collection. Several of these methods of collecting information include a choice of experimental subject. This choice can be executed by adopting probability-based methods, in which the choice is by some "mechanical" process involving an inventory of random numbers, or the equivalent. As an alternative, the choice can be made by other techniques, using some factor of judgement. Methods involving judgement are sometimes known as non-probability selection (Doherty, 1994).

The first step in probability-based selection is to settle on the population of interest and then determine a frame of all the units related to that population.

It is imperative that each element of the frame has a known chance of being chosen, and that it is possible to calculate the probability of choosing the final sample. Also, the sample might be selected in several stages. An important feature of using a probabilistic algorithm to select the sample is that the interviewers have no option regarding who they are interviewing.

To produce the results, the replies from the sample are combined in such a way that takes account of the probabilities of the selection. The point is that, if the sampling were to be replicated for many times, the expected value of the results from the repeated samples would be the same as the result obtained if the whole population was surveyed.

Because the probability is known of getting each selected sample, it is possible to calculate a sampling error for the results. The sampling error shows the amount of variation in the results due only to sampling.

There are also many non-probability based sample designs methods. The key idea in these methods is to generate a sample identical to the target population on definite characteristics. The assumption is that if the sample fits the population on these characteristics, it may also fit the target population on the quantities being measured.

The main difference between probability based and non-probability based sampling is that if the probability-based sampling is executed properly, there will be none of the bias arising from subjective judgements in selection of the sample. The possibility of such bias exists in non-probability samples (Jean-Claude, 1991).

It can be concluded from the comparison between the two methods that the non-probability sampling method is the most suitable for this research project due to the fact that it is based on judgement and a clear identification of participants was not possible. In order to capture a wide response, the survey questionnaire was mailed to a large number of industry related individuals in the UAE in the fields of contracting, consultancy, and academics. The choice of respondents could have more focused and their number reduced however the large number was resorted to in anticipation of the low response rate. To improve the survey conclusions a more precise selection was carried on the received responses and sixty responses were chosen for the analysis based on participant's job title, experience, and completion of survey questions.

e) Computerized model development

The principle input data provided for the project is a set of digital photos from a case study related to an existing building in Heriot Watt University Edinburgh campus. The photos were captured by three cameras located in the directions of East, West, and South taking a photo every minute in jpg format beginning from the first day of construction.

The first task embarked on during the course of this research was to design a platform in C# to which the digital photos were imported. The photos were grouped in three groups each of which represents a stage of the construction process.

There are several available photo enhancement methods, and after trying a number of them, the Image Histogram using MATLAB image processing toolbox was selected.

The available resources from the case study were limited to the digital photos and an original site map was not provided. To overcome this handicap a 3D model was generated using both AutoCAD and 3D Max software to generate a site plan from the sequence of the available digital images. This 3D model was then converted to BIM using Navisworks software.

The BIM was imported to the C# platform for the purpose of providing a comparison with the selected photo to select the relevant stage of construction related to the selected photo. A drop menu appears after the stage selection with several site activities related to the selected stage. When selecting a particular activity from the drop menu, the platform automatically links to the MATLAB image processing program in order to detect the existence of the selected activity in the selected photo. If the activity exists in the photo, then the model automatically provides a choice to either generate the activity and hazard identification form or the risk assessment form.

The software also gives the option to run a number of training videos to enhance the workers safety awareness regarding the selected activity. Figure (4.5) shows the major operations and their inter relations within the computer model.

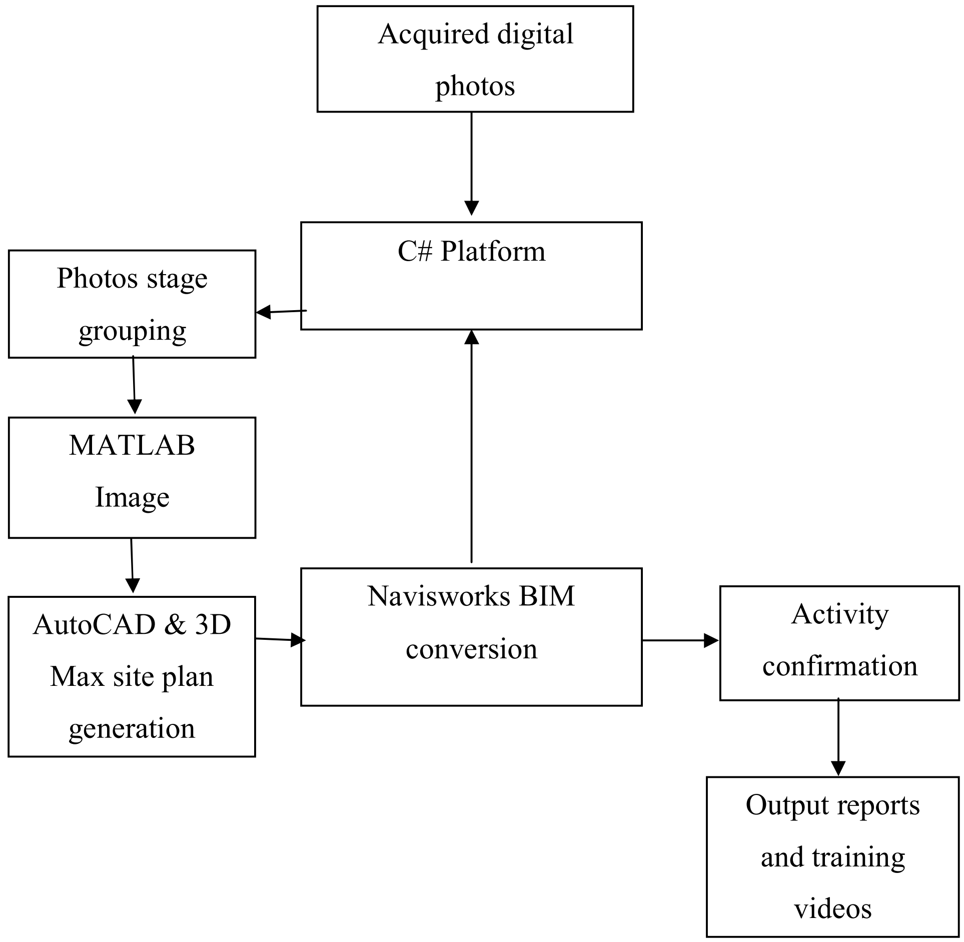



Figure (4.5): Computerized model operations

### *4.4.3 Third stage*

Implementation and validation

Due to the different requirements of each operation in the computer model several suitable software packages and programming languages were selected to best suit these operations. C# was used for loading digital photos and out of results, MATLAB for photo enhancement, AutoCAD and 3D Max for site plan generation, and Navisworks for BIM conversion. The computerized model was specifically developed during the course of this project without modification of any existing package.

The scoring model approach was used to evaluate and validate the computer model modelling program. A demonstration of the model was presented to twenty-four professionals in the construction, safety, and contracting activities in construction companies alongside Academics in Civil Engineering and Health and safety. Some of the demonstrations took place on site at contractor's office while others were held at the Dubai campus of Heriot Watt University. The demonstrations also involved the attendance of interested professionals within the same line of speciality other than those taking part in the survey, who reflected their insight and experience in their comments given during the demonstration however they did not participate in the survey. The survey included answering a questionnaire and participants were requested to give a mark from 1 to 10 for each question. However, to put the results in a better perspective the Experts were divided into three sub categories depending on the relevance of their job position to the subjects included in the questionnaire. The results are discussed in Chapter (8).

## 4.5 Summary

An appropriate and suitable methodology has to be devised for every research work. As described earlier in this chapter there are several strategies covered in the scientific literature. However, each research problem has a specific nature that dictates to a great extent the adoption of a specific strategy which serves to best represent the problem.

The literature review conducted during this study was divided into two main parts. One part was related to the general subjects addressed in this research. These subjects were related to health and safety and computerized project management methods and packages. The second part was more specific in relation to conducting the various stages of the study. It concentrated on image processing and recognition, the building information model, and site safety requirements.

The computerized model was generated specifically for this research and particular attention was given to include the appropriate facilities to make it general in respect of accepting different sets of data and searching for different activities within the data. This rendered the package suitable for many sites applications and requirements of steel construction projects other than the one being the subject of this thesis.

The testing and validation was conducted by a written mailed survey in which local industry specialists took part. The computerized model was also presented to a selected audience whose line of expertise is within the objectives of the model. Their response and feedback helped in providing a practical insight which on one hand brought the attention to developments and modifications to the model, and gave confidence to its usefulness on the other hand.

# Chapter 5- Use of Visualization Tools in UAE Construction Sites

## 5.1 Introduction

The literature reviewed in Chapter (2) together with the closer look on health and safety conducted in Chapter (3) gave an indication as to which subjects are of importance in regards to construction site health and safety hazards and possible methods for their mitigation. A second important fact was the choice of activities that can be modelled, monitored, and influenced within the resources available to this project. These two facts identified the activity of steel structure erection monitored by site cameras with the output data being analysed by image processing techniques as a suitable candidate. The final objective being the implementation of a proactive, effective, and relevant site health and safety training resulting in reducing or eliminating anticipated hazards.

A further advantage that can be obtained from the image data collection, processing, and correlating with construction activities is that it provides the foundation of a project monitoring system. Project progress monitoring and measurement requires putting a project plan in place, Navon and Sacks (2007). The two most important performance elements in the project plan are time and cost. The Architecture, Engineering, and Construction industry has recognized the Building Information Model (BIM) as a suitable model combining the project's activities of cost, time, productivity, and quality.

A crucial fact which reflects on the successful application of any construction management system is the recognition of the basic elements defining a building structure. It was shown that these elements are predictable and that contractors are consistent regarding the rules governing construction activities selection, Gray and Little (1985). Similarities were proven to exist within particular types of construction. With these facts in mind it can be concluded that a standard BIM system can be used.

The project's plan automation problem can be resolved by the application of the BIM as it is based on generating a computerized model combining the project's activities.

Another important activity in the construction industry is health and safety. Steel structure erection is known to be one of the most hazardous site construction activities. Automating the components of the Site's Health and Safety activity will result is a safer working environment. This is due to standardization and the elimination of human errors associated with manual implementation. Automating the health and safety activities on site will result in a safer working environment due to elimination of human errors.

The nature of the construction industry is split vertically between phases and horizontally between specialties, Goh and Chu (2002). This fact resulted in a very large number of information classifications systems based on project's elements such as facility, space, work element, construction product …. etc. Each element includes subclasses like entity, work, lifecycle …etc. (ISO, 1994).

The automation process can be based on providing a digital record derived from the monitoring of an entity (building), work (construction), and lifecycle (steel erection) by cameras. The digital cameras output is analysed by an appropriate image processing software in order to identify the associated safety hazards. Safety reports and training videos can be output also.

The practicality of this approach is dependent on the existence and use of the required and relevant site facilities.

In order to embark on developing the systems and programs required for this research it was necessary to seek practical site experience through a survey. The objectives of the survey were to establish whether digital photography commonly exist on construction sites, if its output is monitored by the relevant staff, and whether it can be useful in site safety training. This chapter is about trying to answer these questions.

### 5.2 Survey Method

The choice of the research approach in a construction management project should be based on the nature of the problem being investigated. The choice should be practical with the target of producing an acceptable solution to the problem at hand Wing, Raftery, and Walker (1998). Following this principle and because the survey was intended to gauge the work environment and plans related to subject, the survey's question did not include requests for detailed information.

In a survey, there are several methods available for information gathering. These methods can be face to face interviews or by remote means such as telephone or postal surveys. Postal surveys can also be by mail or electronic. Since the goal was to achieve the widest possible participation and the geographic locations of participants, the electronic mail option was chosen.

The chosen method of electronic mail has its drawbacks. A mail questionnaire survey typically lacks the depth in its questions. The fact that it is addressing participants of different jobs classifications and various qualifications necessitates its general nature. Furthermore, the surveying party has no means of ensuring that respondents had truly understood the questions and do not have the ability to seek clarifications if the answers were ambiguous. There are a number of suggestions in the literature which target improving the response rate, Root and Blismas (2003). In order to maintain consistency, most of the questions were of the closed type with the exception that within some closed questions the open option of (others) gives room to participants who have answers which cannot be included in the closed alternatives provided. In two cases related to the use of photos in accidents investigations and the frequency of review of the site's safety plan the questions were open.

A survey was conducted to investigate the existence and extent of use of construction site digital cameras in existing construction sites. Another target of the survey was to collect information on the health and safety briefings and training given and their relation to the planned daily construction activity.

The questionnaire in (Appendix A) was electronically mailed covered with the email shown in (Appendix B).

## 5.3 Survey objectives

The survey objectives were related to two main areas:

A) Digital photos acquisition and use in the various site construction activities.
B) Labor awareness of the hazards associated with their specific day activities.

Within the first theme, the frequency and purpose of reviewing site photos was investigated. The second theme included the site safety plan, its understanding by the workers during their daily jobs, impact of safety training, and the advantages of visual tools in safety training.

The obtained information is intended to assist in the evaluation and the practicality of the model section related to the image processing, reports output, and training videos parts within the overall modelling process.

## 5.4 Survey invitations and responses

A questionnaire including fifteen questions was mailed to a number of construction industry related firms selected from those operating in the UAE. Responses were received from sixty (60) firms whose activities are shown in Table (5.1):

Table (5.1): Firm activities of questionnaire respondents

| **Activity** | **Number** |
|---|---|
| Consultants | 39 |
| Contractors | 18 |
| Others | 3 |

The responding companies forwarded the questionnaire to one of their staff or departments however the responses received were from individuals within these companies. The individual respondent's job titles are shown in Table (5.2):

Table (5.2): Respondents job titles

| **Job Title** | **Number** |
|---|---|
| Project management | 28 |
| Health and safety | 29 |
| Site administration | 2 |
| Others | 1 |

## 5.5 Survey results

- The fifteen questions presented in (Appendix A) addressed four main topics the first two of which are related to area (A) and the later two are related to area (B) of section (5.3). These topics are: Site digital cameras.
- Site use of visualization tools
- Construction company health and safety plan.
- Labor awareness and daily briefing of job hazards.

The respondents were requested to answer the questions listed in the questionnaire however not all respondents answered all questions. The open nature of questions (4) and (7) of the questionnaire is such that different answers that are difficult to group are received from respondents reflecting their specific procedure. The survey results and their mathematical analysis are presented in (Appendix C). The variation in the number of respondents for each question may be attributed to the fact that the question is not related to the respondent's line or type of work. The figures summarizing the results are presented in the following sections classified as per the survey objective areas stated in section (5.3).

### *5.5.1 Survey results related to existence and use of site visualization tools:*

The purpose of the first two questions in the survey was to establish the existence of site visualization tools in the form of fixed or portable digital cameras. Establishing the number and percentage of sites with visualization tools helps in justifying the development of a system based on their output. Figures (5.1) and (5.2) show the number of sites equipped with site visualization tools. The results show a clear preference to portable rather than fixed cameras. This could be attributed to the fact that construction is a progressing activity and the monitoring focus shifts to different places thus the deployment of portable cameras becomes more economical.

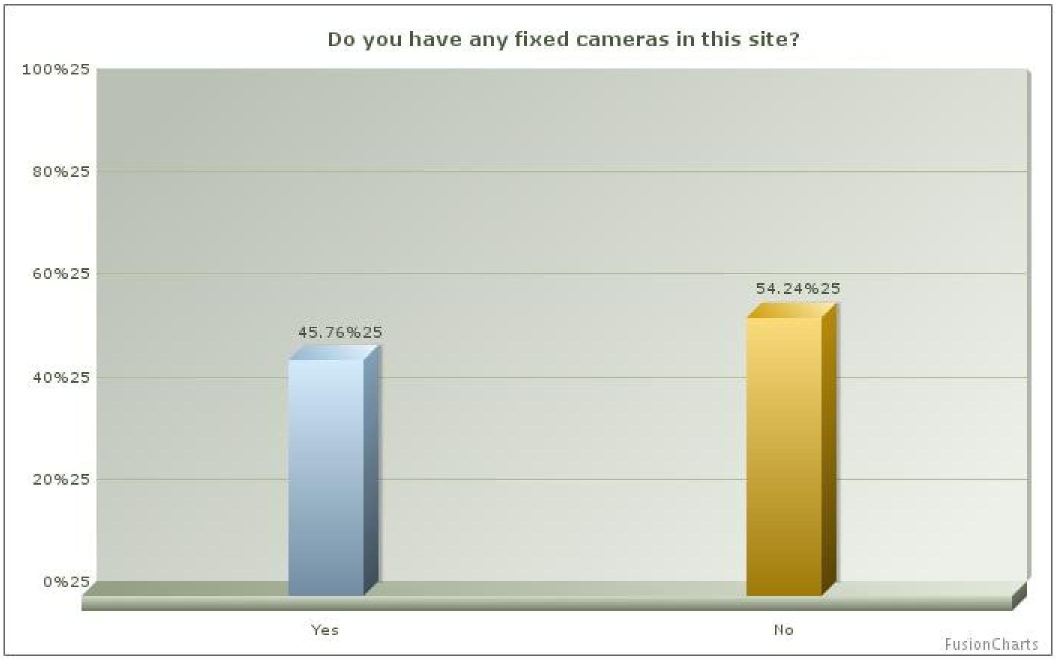



Figure (5.1): Fixed cameras on site

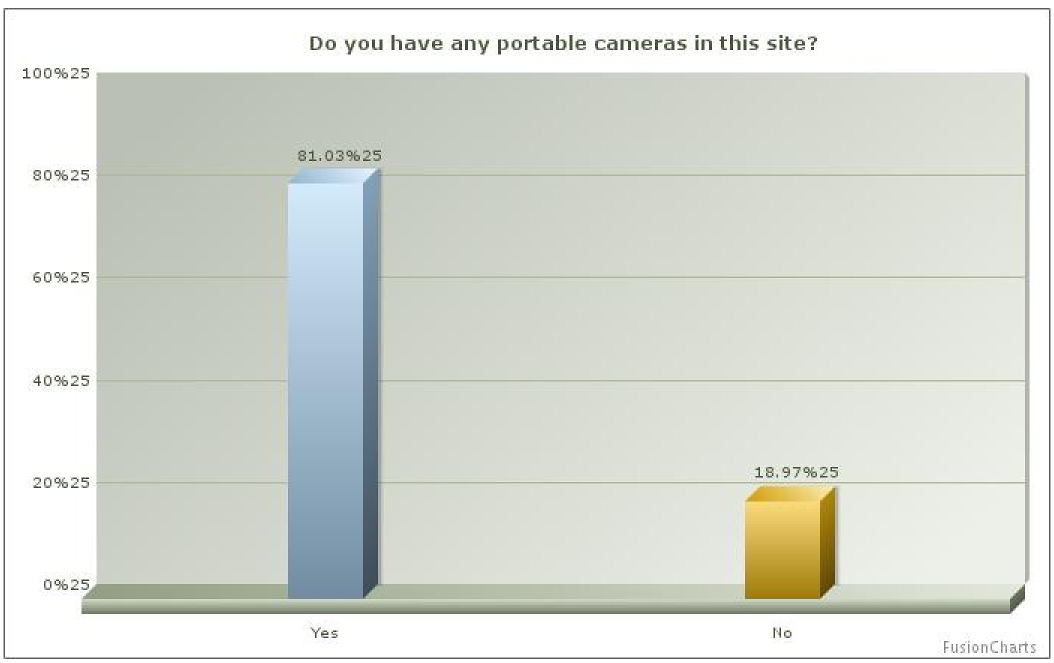



Figure (5.2): Portable cameras on site

The installation of the cameras without a work system dictating the frequent review of their output reduces their use to recording only. This will deprive the user from any interactive or proactive action similar to the one intended in this project. Figure (5.3) reflects the frequency of reviewing site cameras output.

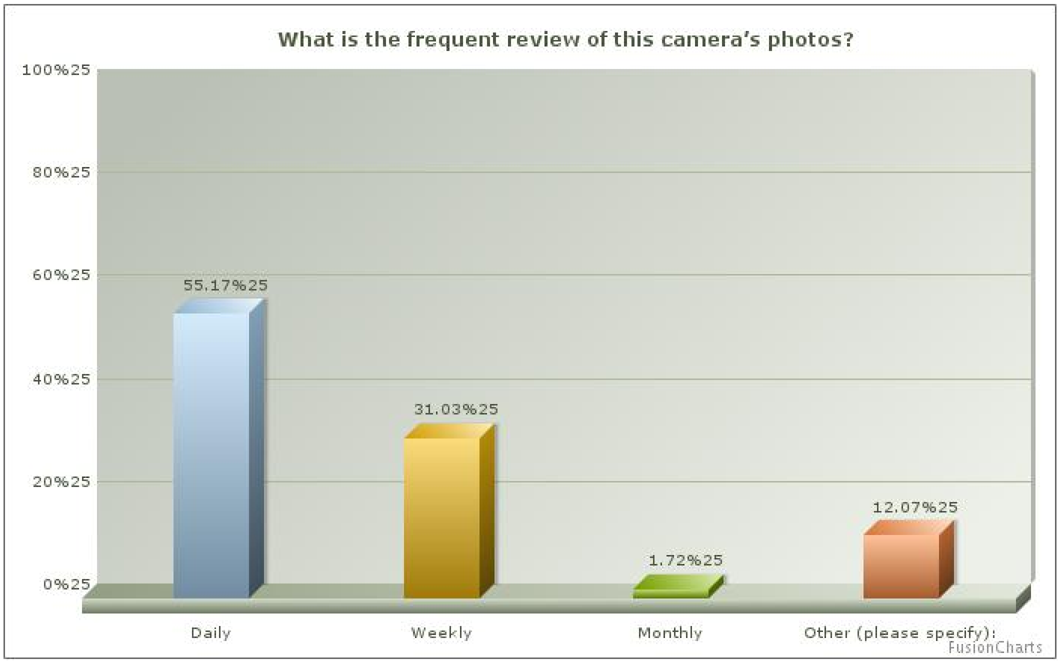



Figure (5.3): Frequency of photos review

### *5.5.2 Survey results related to the use of site visualization tools output:*

The purpose for which site visualization tools are installed and the review and follow up of their output is important in justifying the aims of this research project. A safety plan needs to be in place which includes designations, policies, and work procedures. This plan should define accidents preventive measures and designate the party whose job is to enforce compliance with site H&S rules. The ROSPA Occupational Health & Safety Awards (2002). Figure (5.4) reflects the encouraging result that almost all the surveyed projects have an approved site safety plan.

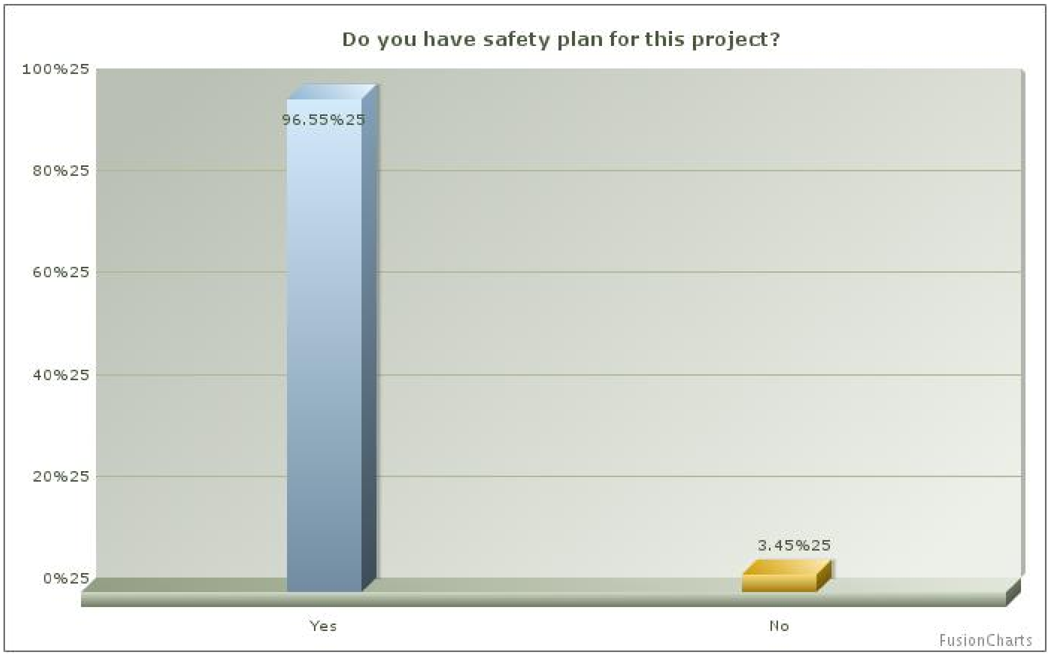



Figure (5.4): Site safety plan

A method of monitoring the compliance with the site's safety plan is by the use of site cameras. The survey sought to establish if this method is being recognized and included in existing safety plans of projects under construction. Figure (5.5) shows the percentage use of site camera output for the purpose of safety monitoring.

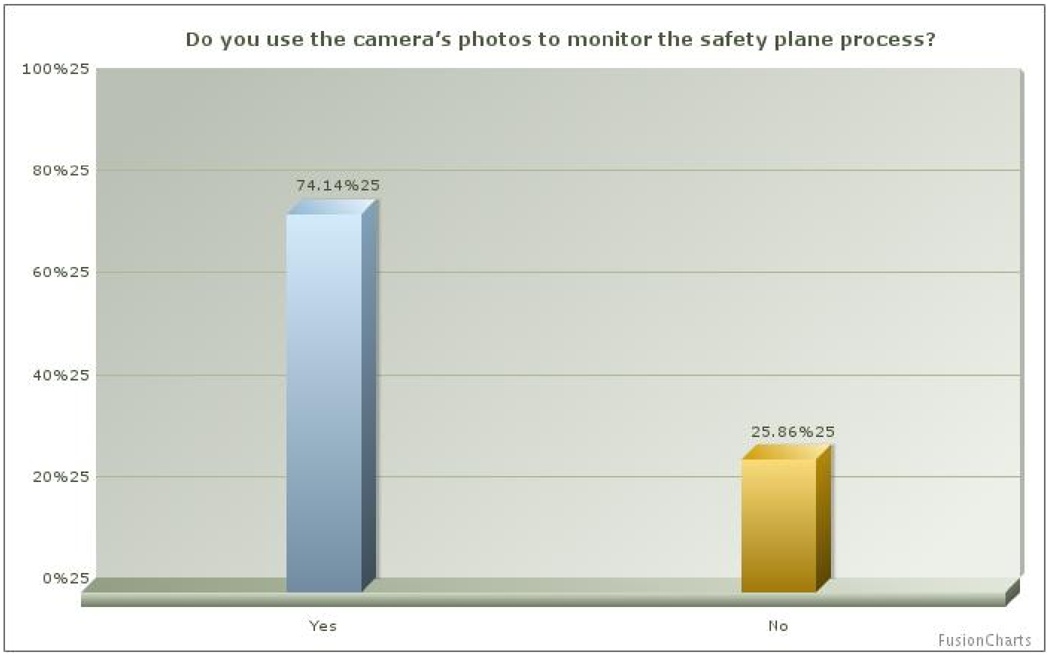



Figure (5.5): Relation between photos and site's safety plan

In order for the monitoring activity to be interactive, the image outputs need to be reviewed frequently and any learnt lesson or experience drawn from this exercise is incorporated as a revision to the site safety plan. Figure (5.6) reflects the frequency of review of site cameras output for the purpose of improving the site's safety.

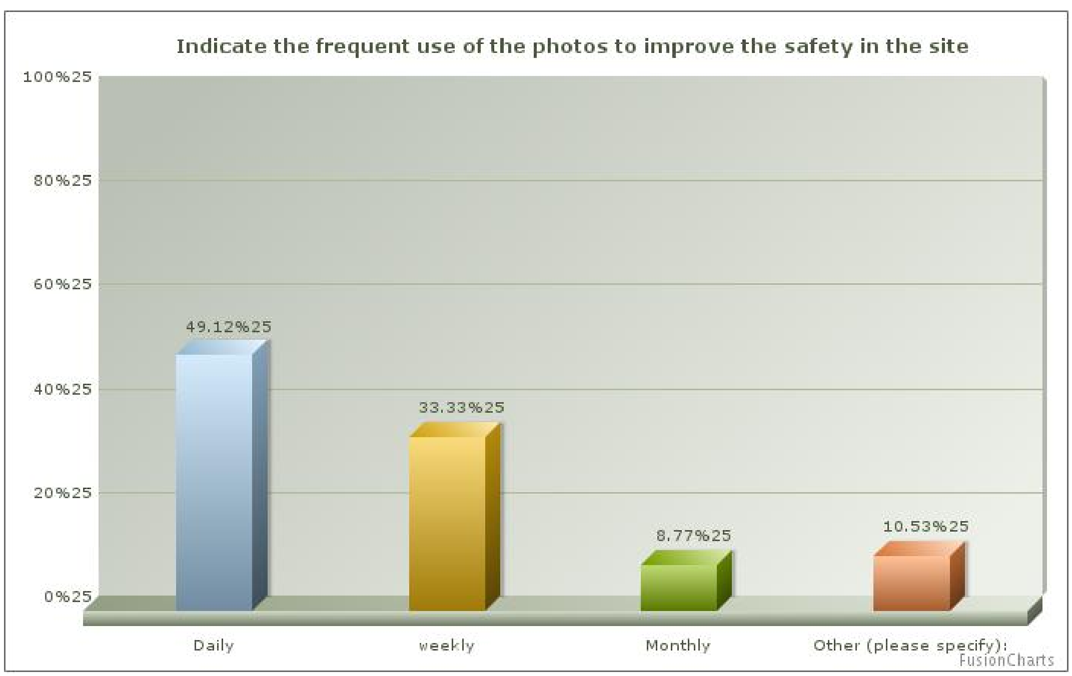



Figure (5.6): Relation between using photos and improvement in site safety

The following questions in the questionnaire were designed to evaluate the labour safety awareness. Anticipated hazards are associated with the type of the daily job being carried out. Figure (5.7) reflects an encouraging outcome which can assist in selecting the suitable site training method for these specific daily jobs.


Figure (5.7): Labour awareness of daily activities

It is not enough for the labour to be aware in general of their daily jobs. Detailed awareness improves the way in which they perform their jobs and results in a better safety record. The importance of this information is in its relation to the extent and nature of the proposed site training envisaged in this project. Figure (5.8) reflects a high percentage of relatively high level of job awareness.

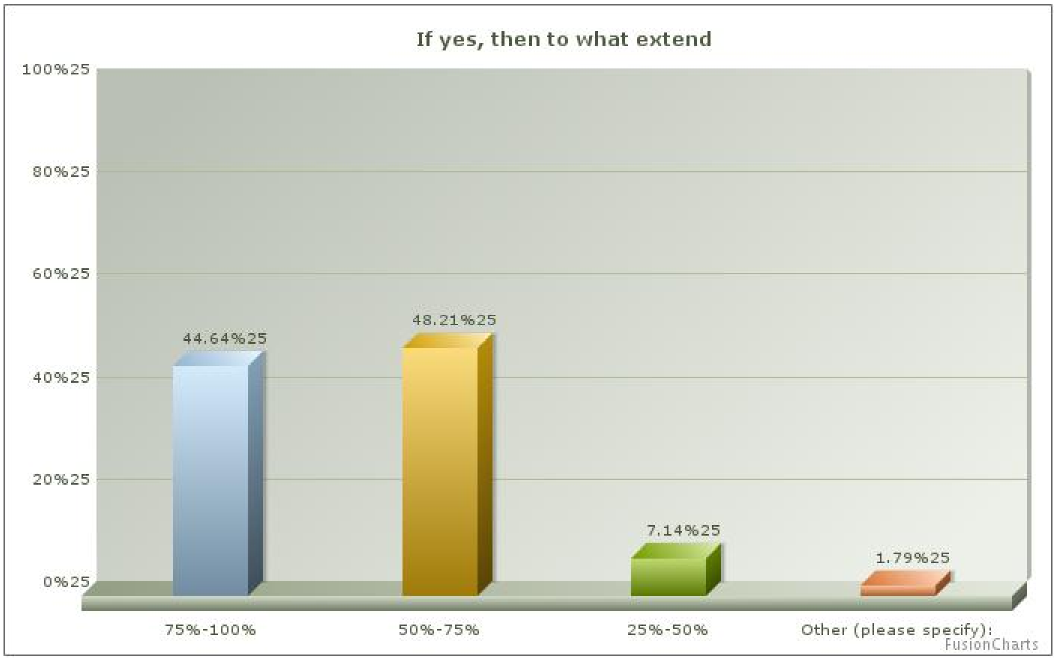



Figure (5.8): Depth of labour awareness of daily activities

The next level of labor awareness is related to the associated hazards with their planned daily job. Knowing the nature of the possible hazards will drive the labor to be more careful in carrying out the hazardous jobs and move away from any action that might contribute in their triggering. Figure (5.9) reflects the level of labor general awareness regarding the field of steel structures being the topic of this research.

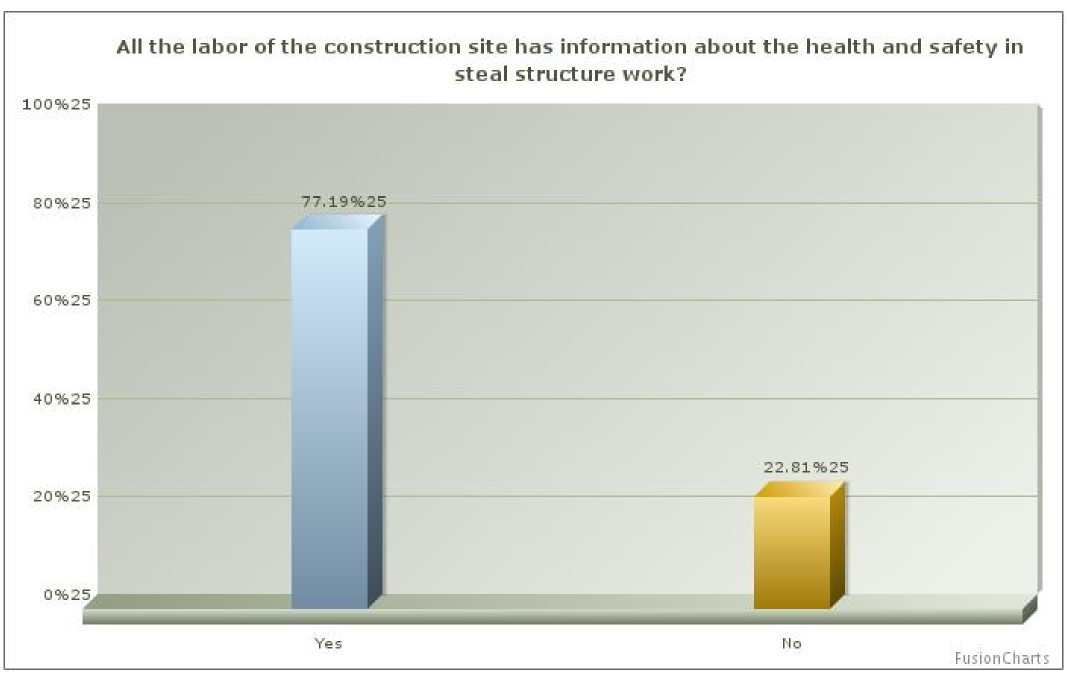



Figure (5.9): Labour awareness of health and safety in steel structure works

The field of steel structure construction includes several specific activities. The labour's daily job is usually associated with one or at a maximum few of these activities but never all. Therefore, it becomes important to know the level of labour awareness to the hazards and methods of preventions that are associated with their daily activity. Figure (5.10) reflects a satisfactory level of awareness.


Figure (5.10): Labour awareness of hazards and hazard prevention

The next area of interest in this research project is the reflection of labour training on the site safety performance. The project envisages the deployment of targeted training material related to the specific daily activity and on the same day before its execution. It is important in this respect to establish whether a daily safety briefing is being practiced and if site visualization tools are part of that exercise. Figure (5.11) indicates that daily safety briefings are not all that common which is to be noted eventually when presenting the safety package software being developed in this project to the industry.


Figure (5.11): Labour training for daily activities

The use of site visualization tools and the deployment of their output in safety training are shown reflected in Figure (5.12). The results indicate a gap in this respect which should be noted and highlighted to the future users of the developed software package.

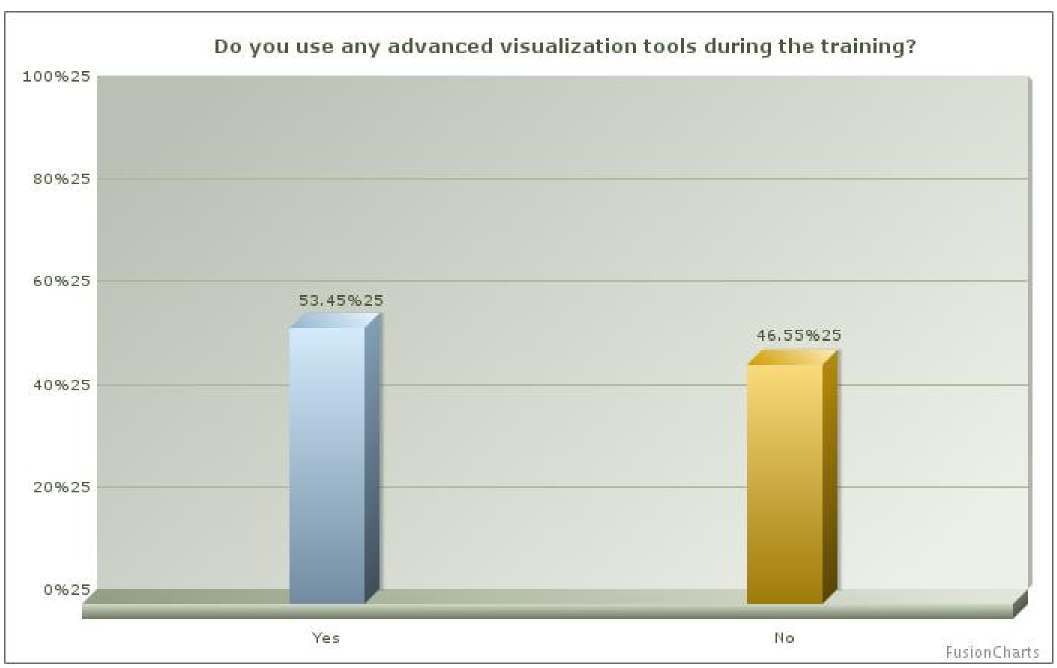



Figure (5.12): Use of advance visualization tools in training

Finally, Figure (5.13) puts a subjective question to the survey participants. It is meant to make use of the participants' knowledge and experience in validating the results of the approach sought in this research project being interactive daily on-site training of labour by using the output of site visualization tools. The very high percentage of approving is taken to be a positive sign for carrying forward with the project.

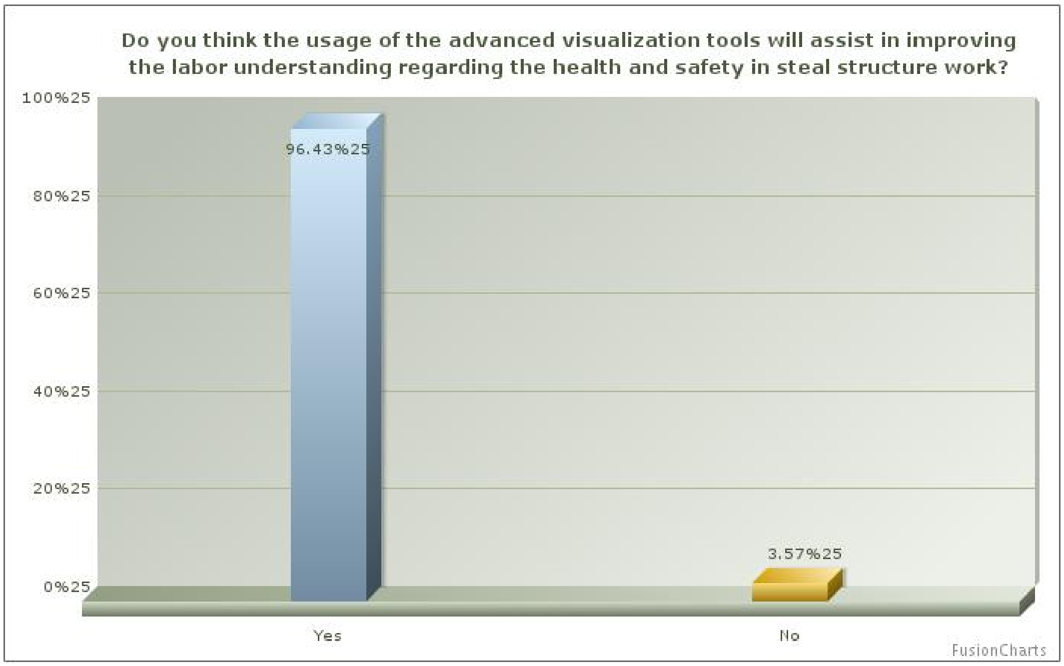



Figure (5.13): Improving health and safety by using advanced visualization tools

## 5.6 Discussion of survey results

The conclusions drawn from the survey can be grouped in four major topics:

- Existence and use of cameras in construction sites.
- Impact of cameras output on site safety programs.
- Reflection of cameras output on the awareness of site labor.
- Use and effectiveness of visual training tools.

### *5.6.1 Cameras on construction sites*

The results of the survey show that 81.03% of sites have portable cameras out of which 35.27% have both fixed and portable cameras on site. This is an encouraging result reflecting the growing importance which construction firms are basing on site cameras output in various construction activities. It also confirms the ability to use computerized models based on digital visual outputs such as the one being developed in the course of this work in various project management activities. However, the frequency of the review of the cameras output is equally important. In order to make full benefit from the data made available by site cameras their review should be daily and part of the mandatory work protocol. Sixty percent 55.17% of surveyed firms indicated daily review of site camera photos. This shows a reasonable level of intention in making use of the information. A relatively high percentage of 31.03 % indicated weekly review which will limit the use to recording and investigations. The percentage of firms that have no cameras or do not review their output is 12.07%. Although this percentage is low in absolute terms, it is surprisingly high in an atmosphere where site digital monitoring is becoming an industry standard.

### *5.6.2 Relation between site cameras output and safety*

The impact of cameras monitoring on the sites safety was measured by the frequency of interaction between the two. The results show that 50% of surveyed sites use the daily visual outputs in reviewing the safety conditions on ground. This is a very positive result indicating the importance the site management bodies assign to data collected from cameras. It also confirms their viability as a management tool. The specific accident investigation task represents 25% of cameras output results. This task falls under the recording activity rather than the interactive activity which makes the best use of the available output data. However, it is also very important and effective in resolving accidents claims and disputes.

A relatively high percentage 25% of sites hardly makes any use from installed cameras by not reviewing their output periodically but only when needed to review a specific incident. This limits the return on the investment of installing the site camera system to a narrow use which has to be evaluated in conjunction with the benefits resulting from their application. The result confirms that there is some way to go yet before site camera outputs become an integral component as a site safety tool.

### *5.6.3 Integration between site safety plans and cameras output*

Over ninety six percent 96.55% of the surveyed sites confirmed that they have a site safety plan in place for the construction project. This is understandable as it is a requirement for granting construction permits. The remaining 3.45% represents a small project that does not have a dedicated plan but within a bigger construction site that has an overall plan.

It was of interest to know how often if at any time the safety plan is reviewed due to developments on the site during the lifetime of the project and if any of these revisions is attributed to the output of site cameras. 37.5% of the result showed that the site safety plans are being daily or weekly reviewed and updated. Another 35% showed revisions to the plan that are not so frequent and mainly on monthly basis.27.5% of the results showed that the site safety plan revision is not a timely activity. It is performed under special unforeseen circumstances like introducing a new activity, a new law or regulation, a high accident frequency range, change in environment …. etc. A change in organization or management also triggers a site safety plan revision.

A high percentage of 74.14 % was associated with the use of site cameras as means of monitoring the execution of the safety plan in place and thus flashing any need for its revision.

### *5.6.4 Enhancing safety awareness among labour*

Labour in low level jobs on construction sites are sometimes illiterate or migrant labour. These two categories represent a challenge for management especially regarding the health and safety site requirement. Although they could be well qualified to do their daily jobs, they might have different background experiences regarding the health and safety site conditions. Using still and video footage to drive a point is time saving and overcomes the language barrier in case of a foreign or illiterate work force.

The survey highlighted the difference of the level of awareness of the daily job execution requirements and the associated safety requirements. 92.98% of the workforce was shown to be aware of the day's job activity to various levels. 44.64% had over 75% awareness of the job execution requirement against 41.38% regarding the associated health and safety requirements. For the lower level of 50%, the job awareness was 48.21% versus 53.94% regarding health and safety. Although the results seem to be close however they point out that labour are not on the same level of awareness regarding their work job requirements and the associated health and safety requirement.

### *5.6.5 Use of visualizing tools in training*

The survey, in line with the work objectives, focused on the activity of steel structure erection being easily recognized from imaging and represents a high source of site health and safety hazards. The safety issues associated with this activity are of a special nature and labour should be advised regarding these specific issues. It was seen that only 77.19% of the labour force associated with this activity were informed about its risks. This is an indication for the need of further training. This fact is further highlighted when looking at the results of labour's training frequency. Only 65.52% of the work force is trained daily while 34.48% are not regarding their daily work jobs. The daily training is very important as it concentrates on activities that will be performed after a short period of time while the information is still fresh in labour's minds.

Daily training using safety leaflets or briefings is not effective due to logistic and cultural barriers. Visual photo or video material can drive the training points more efficiently and quickly. The survey showed 53.45% sites adopting visual tools against 46.55% that do not. The reasons cited were the unavailability or difficulty in application of the visual tools. This result is another indication that automated easy-to-apply visual training tools are highly needed, which is shown in the last result indicating that 96.43% of participants agree that they will assist in improving the present health and safety site conditions.

## 5.7 Conclusions

The survey was conducted in order to acquire the practical feedback from the relevant professionals in the steel construction industry regarding the components of the research project which is being carried. It is important to know whether the site visualization tools, on whose output this project depends, are installed, monitored, and their output is reviewed and analysed. It is also relevant to the project to understand if the nature, type, and frequency of the training which is being provided to labour on site and whether visual methods can enhance it.

The results indicated decisively the existence of site visualization tools in the form of fixed and portable cameras which is important for obtaining site digital data. This digital output was also seemed to be reviewed frequently and a site safety plan is in place. These results are encouraging as they establishing the existence of the fundamental basis on which this project work is based on. The digital data forms the input to the software envisaged in the project and is used in the image recognition process for tasks and hazards detection. The existing safety plan can be the platform on which the programmed visual safety sessions are launched.

The survey indicated a gap in the use site cameras for monitoring the implementation of the safety plan. This is an area which is being addressed in this project and shall be pursued by coming up with a solution that will be able to bridge this gap. The solution shall be based on using site digital image analysis and recognition in identifying specific anticipated hazards resulting from the failures in implementing the site safety plan.

The site safety record depends on the labour's awareness in respect to the job they are performing and its associated hazards. The survey indicated another gap in the labour awareness in relation to the hazards associated with the daily job being performed. The project has this problem in consideration and is proposing to cure it by focusing on providing visual daily training to labour tailored to the work job to be implemented.

# Chapter 6- CONSTUCTION AUTOMATA: A Visual Software Model for Safety Enhancement in Steel Construction

## 6.1 Introduction

Chapter (3) revealed that steel structure construction is one of the most hazardous activities on a construction site. It also indicated that these hazards and risks can be mitigated by the relevant workers training. The training instructions need to be fresh in workers minds when embarking on their daily jobs which meant that a proactive approach tying the design, activities schedules, and past experience has to be adopted. The hypothesis is to achieve a system representing this approach is the utilization of site image acquisition and processing and integrating it with the design and work schedules. This sought objective can be realized by joining two separate activities through a suitable modelling system. The first activity is image acquisition and processing, and the second activity is the project digital design and time schedule. The modelling system results in a 4D model suitable to be displayed.

This chapter seeks to discuss briefly the theoretical background related to the different components of the developed model. The last part of the chapter is dedicated for the Construction Automata model development process.

## 6.2 Theoretical background

Construction is a knowledge based industry in which people from different professions and different organization join together for the common target of completing a project. This fact requires the efficient organization of knowledge which can only be achieved through a sophisticated system of knowledge management.

Knowledge management is the process of capturing, collecting, storing, coding, and accessing for the person using this knowledge in order to support solving problems and taking decisions in any situation that requires sharing and accessing of intellectual capital. As only the knowledge of explicit nature can be codified, the management of knowledge entails converting tacit knowledge into explicit knowledge and saving a database with different type knowledge for reference. In order to understand this knowledge database, certain skills are needed in interpreting and evaluating the information provided to be able to understand its meaning. The knowledge needed for an organization is a valuable asset and should be managed in such a way to be retained within the organization. Good management results in compiling information obtained from several sources into a collective data base belonging to the organization, Valappil (2012).

Although the knowledge management's importance is well recognized in the construction industry there is no available system that visualizes its different types of elements as a part of a process of automating the creating, saving and distributing knowledge in a holistic approach. Thus, it can be said that there is no implemented formal management process for controlling knowledge regardless of its implications to participants, Valappil (2012). This fact provided the grounds for embarking on this research project.

Knowledge management is composed of four major disciplines which are acquisition, storage, dissemination and application. In order for users to access the right knowledge at the right time, a system of teamwork communications should be in place, (Valappil, 2012).

Steel construction requires a document management system to track revisions and identify the parties involved in issuing of any document thus providing an efficient control platform in this industry, Kanapeckiene et al. (2010). This system also helps to preserve the gained experience and make it available in any other similar project thus preventing critical mistakes from happening again, (Valappil, 2012).

Information Technology (IT) application provides the tool to capture the relevant required information and relay it to the correct destination, eliminates the geographical linkage by deploying the intellectual capital throughout the organization's sites, and spreads the knowledge through the team members of an organization allowing larger project teams to participate (Kanapeckiene et al., 2010).

Building information modeling (BIM) is an information technology based knowledge management system that generates computerized n-dimensional models for the active planning, designing, constructing, and operating of any project. This interactive environment is capable of identifying potential problems associated with the design, construction, or operation before being faced in reality. It also provides working integration and harmony between all the disciplines involved in the project rendering them to work as one team rather than adversaries (Azhar et al., 2008).

The 3D CAD design model data are represented as graphical entities such lines or circles while those in a 4D model are stored as “smart objects” with all data regarding specifications, supplier, and operation and maintenance procedures (Azhar et al., 2008).

Construction Automata is a 4D project knowledge management model resulting from incorporating the 3D CAD design of a steel structure construction project with the approved project schedule. The automatic safety report generation facility incorporated in it allows the storage and retrieval of material related to faced hazards and accidents that are related to specific work activities thus providing a base for a knowledge management system. The model can also be developed further to include other project management activities to generate a full BIM model. This further development is not part of this research project. Construction Automata input data is a set of digital images of an existing steel structure project. These images need to go through an image analysis and recognition process in order to be identified with the digital information in the 3D CAD project’s design.

A ’Digitalizing Construction Monitoring (DCM)’ integrates 3D CAD drawings with digital images interactively by extracting 3D digital images and comparing them with 3D CAD models hence extracting work progress information (Abdmajid et al., 2004), (Memon et al., 2005), (Memon et al., 2006).

A similar application using the library which contains the full list of elements of the 3D model of the building is also available (Bayrak and Kaka, 2004).

Digital image processing had been a research topic for some time. Its basic concept is that a digital image is pixels collection filled with a colour that is digitally defined, in order to define it as a 3D matrix (x, y, and colour). The pixel coordinates are specified in the first two X and Y dimensions while the third dimension defines the pixel’s colour. The first two dimensions represent the coordinates of the pixel and the last dimension defines its colour (Abeid and Arditi, 2002).

The safety enhancement in steel construction sought by Construction Automata is achieved by visual site safety training of labour related to expected hazards associated with their scheduled daily activities through a process of simulation.

Simulation is introduced and extensively used for the simultaneous improvement of several aspects of training by broadening the range and improving the effectiveness, (Mawdesley et al., 2011).

Training simulation is whereby actual trainees use training systems in a real environment.

A steel construction training simulation package is developed through the following steps: (Davidovitch et al., 2008)

-Goal identification.

-Choosing a scenario suitable for simulation.

-Strike a balance between complexity and reality.

-Incorporate monitoring within the software.

-Checking the package for effectiveness.

A significant improvement to virtual training can be achieved by linking the stored information contents to simulating and graphic applications in order to enhance their dynamic interaction capability, Addison et al. (2013). Dramas and animations are used to simulate accidents and provide a training venue which helps minimize site accidents in a more effective way than theoretical training. This is especially important in the case of low education level workers at entry positions in the construction industry, Addison et al. (2013). This was a major factor in choosing the training method incorporated in Construction Automata.

## 6.3 Rational for Construction Automata development

The steel construction industry accounts for 5% of the general working force but it results in 22% of the fatal injuries and 10% of major injuries which are substantially bigger than its share indicating its dangerous nature, Health and Safety Executive (2013). The construction site safety hazards and accidents in this industry have a significant financial impact on projects which can jeopardize their economic viability.

Estimated project's cost can be better controlled when risk and hazards are reduced or eliminated. Costs overrun will result in diminishing the profit margin of the contract and renders it not attractive hence a dedicated commitment by all parties involved in any project will significantly impact its profitability (Emmons, 2006).

A significant reduction in fatalities and major injuries is being witnessed over the last years due to the improved adherence to guidelines and regulations, Health and Safety Executive (2013). Safety improvement approaches yielded positive results by reduced construction industry accidents with a drop of 22% in fatalities and 55% in days away from work during the period (1992-2005) in the USA (CPWR, 2006).

Lack of proper training and knowledge about health and safety issues are the main causes of accidents in steel structure construction sites. This lack of training is a result of poor safety and health management thus implementing an effective training program has a great potential to minimize these accidents, (Arslan and Kivrak, 2009**).**

The majority of health and safety trainings given to construction workers consist of theoretical trainings. Since the majority of the construction workers have a low education level, learning the health and safety concepts with theoretical trainings are quite difficult for these workers. Therefore ,dramas and animations that have the potential to make trainings more attractive and enjoyable, can overcome this problem, Hick (1997). The training exercise by dramas and animation is used to present work place accidents demonstrating what went wrong and how to avoid it.

The first part of the exercise is the data collection of previously recorded accidents regarding their causes, numbers, and frequency. Statistical data published by governments, professional institutes, and nongovernmental organizations are available and can serve as basis for this exercise. The data is then grouped under several headings such as their frequency or their severity, Arsalan and Kivrak, (2014). In the second part accidents scenarios are prepared where construction accidents are defined in terms of causes, frequency, places …etc. These scenarios should also address precautionary and preventive measures which should be taken. The following part is the designing of the drama and animation in which an innovative effort is needed to create the material which is presented in different levels of importance and for various types of works. This approach will help in preparing specific different training dramas for each work category. Computer animations constituted from images and musical rhythms without a spoken language can serve an international audience, Arsalan and Kivrak (2014). The last part is the applications of the dramas in the health and safety training programs.

Construction Automata seeks to make advantage of this approach by its ability to create a specific accident scenario and preventive measure for a specific job activity and give the visual training on site before carrying the activity by the workforce.

### 6.4 Aims and objectives of Construction Automata

The aim of developing the Construction Automata model is to generate a computerized project's site safety management system based on integrating site images processing and recognition software with 3D CAD digital project's design documents. Review previous research addressing the issues regarding safety in construction.

1. Develop a system which incorporates real time work progress imaging together with the applicable of site safety standards, codes, and requirements.
2. Selecting a high-risk profile and an easily defined construction activity.
3. Develop or adapt existing suitable and specialized computer software to perform the image recognition and comparison activities.
4. Develop a knowledge management system based on recording and investigating the health and safety performance in construction projects using the output and feedback from the developed specialized software.

The Objectives behind the development of the model are:

- Develop a knowledge management software model which integrates steel structure work progress digital images together with the applicable site safety standards, codes, and requirements.
- Using photographic data and image recognition analysis techniques for hazards detection in the field of steel construction safety.
- Building a four-dimensional model incorporating the three-dimensional image data available from an actual 3D CAD design of a project, indexing all real images taken, searching and retrieving selected time images and comparing them with the rendered project design model.

- Foresee future activities on site by utilizing the project work program and identifying the associated site risks and hazards.
- Identify safety problems and danger of injuries associated with a specific daily job within a steel construction projects.
- Provide visual safety training material relevant to the identified safety problems.
- Automatic relevant safety reports storage, output, and display via an advanced visualization tool to serve as basis for knowledge management.

## 6.5 Construction Automata model overview

The purpose of modelling is to make a particular activity easier to define, understand, visualize, quantify, or simulate. It requires the selection and identification of relevant aspects of the activity and applying different types of models to meet several objectives such as conceptual models to better understand, operational models to operate, mathematical models to quantify, and graphical models to visualize the activity, Tolk (2015). It was determined earlier in this research project that steel construction is a very high risk activity in the construction industry which suffers from lack of modernization in addressing its safety requirements. In an attempt to bridge this gap, a computerized model (CONSTRUCTION AUTOMATA) was developed to identify risks associated with specific work activities and provide the relevant safety instructions and training to mitigate them. The model automatically produces safety reports to record and serve as data base for future reference thus eliminating possible human errors.

### *6.5.1 Model flow chart*

The model's flow chart shown in figure (6.1) reflects the main components of the model and the relations between them. The two streams input consists of the 3D CAD design integrated with the project's program forming a 4D model and digital site image photos are placed on compatible software platforms for the image processing operation to identify the daily work activity and accordingly the safety hazards associated with this activity. The model's output is displaying the relevant safety training material in an advanced visualization tool and the automatic generation and output of the relevant safety report.

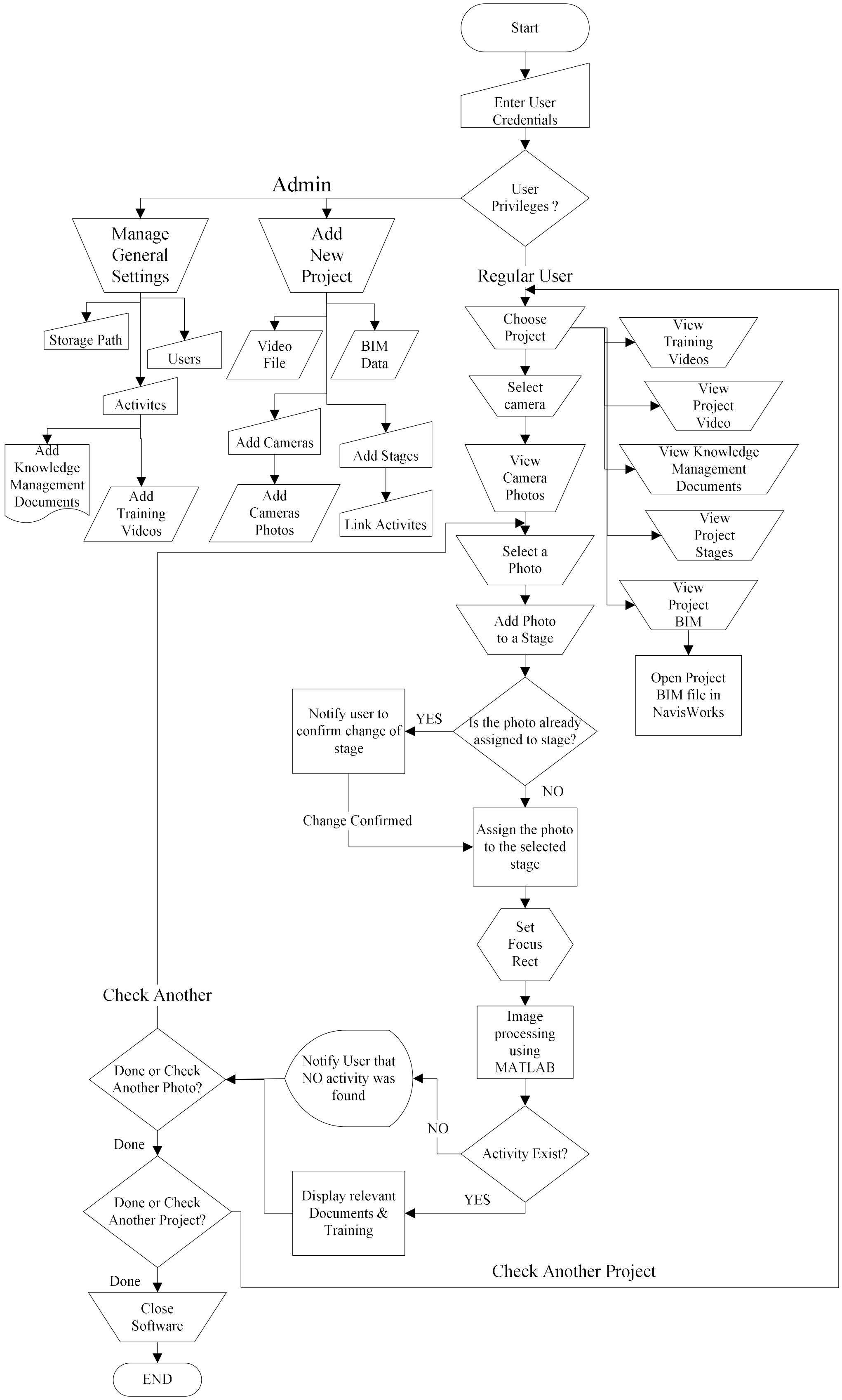



Figure (6.1): The model's flow chart

The end users targeted by the model are steel structure construction personnel with adequate knowledge of site construction stages, health and safety general requirement and site health and safety plan, and relevant computer skills. As per Construction Automata the end users fall under two groups, the general user group and the administrator group. The general user can navigate through the software windows of the model, edit information, add components, and view reports. The general user group access is limited to one project of interest. The administrator group can add, remove, or edit projects. They also can edit individual components of projects.

## *6.6* Construction Automata development strategy

System Development Life Cycle (SDLC) is a process used to design, develop and test high quality software and has three main objectives namely to ensure the delivery of high quality systems, provide strong controls for management in relation to the projects, and maximize staff's productivity.

There are various software development life cycle models which are followed during the software development process also referred as "Software Development Process Models". Each process model follows a Series of steps unique to its type, in order to ensure success in process of software development. The most important and popular SDLC models followed in the industry are:

- Waterfall Model: which comprises phases to be completed sequentially in order to develop a software solution.
- Spiral Model: which is visualized as a process passing through some number of iterations.
- Iterative Model: is any combination of both iterative design or iterative method and incremental building model for software development.

The Waterfall Model was the first Process Model to be introduced and is very simple to understand and use. In a waterfall model, each phase must be completed fully before the next phase can begin. This type of software development model is basically used for projects which is small with no uncertain requirements. In waterfall model phases do not overlap. The advantages of this model are: (Alshamrani and Bahattab, 2015)

- Easy to understand and implement.
- Widely used and known.
- Minimizes planning overhead.

- Phases are processed and completed one at a time

Based on this analysis the Waterfall SDLC model was chosen for this research project. Figure (6.2) shows the steps that need to be taken to complete the SDLC cycle, (Bender RBT Inc., 2003).

The first three steps are of a general nature in regards to the developed project's model. They are intended to narrow the field in order to focus on the subject which shall constitute the core of the model. This can be done by market research, questionnaires to relevant parties, and the targeted industry development needs and requirements.

The remaining three steps are more of a particular nature in regards to the development of the chosen model's requirements. This fact necessitates reviewing them under independent articles.

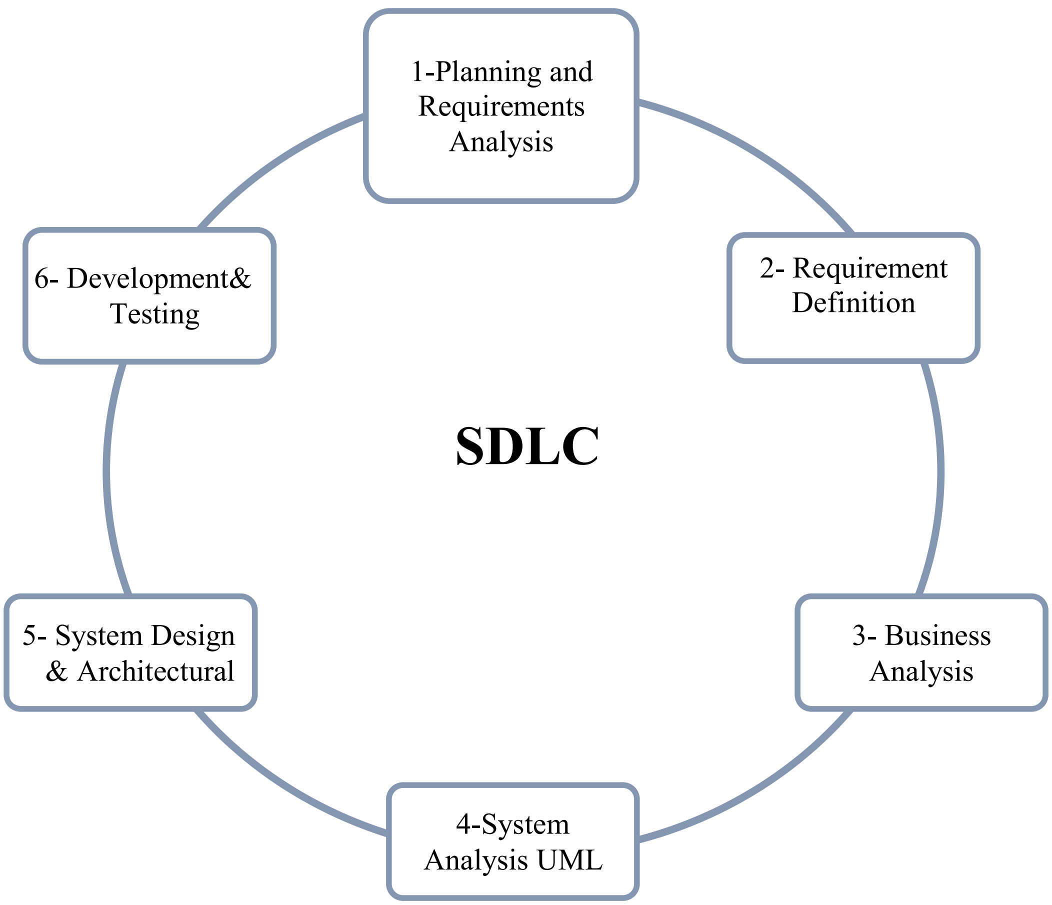



Figure (6.2): The SDLC steps

Step 1 Planning and requirements analysis: Requirement analysis is the most important and fundamental stage in SDLC. It determines whether a new system is needed to cover a specific objective. It represents a preliminary feasibility study or plan related to a specific business initiative in order to justify allocating the resources needed. The purpose of this step is to define the problem and considers the costs, time, and benefits obtained from finding a solution.

The specific problem addressed in this project is the steel structures construction activity as it continues to be one of the most hazard jobs in the construction industry. Planning for a system to enhance the worker health and safety awareness is needed especially for low-skilled worker.

Since the construction process is divided into multiple stages, each stage with different activities, the developed system needs to detect activities existence which can be obtained from site photos

The related activity information is then used to conduct the required analysis in the economical, operational, and technical areas in view of defining the various technical approaches that can be followed to implement the project successfully with minimum risks.

Step 2 Requirement Definition: The second step is to clearly define the product requirements and get them verified by the end user. The possible solutions for the specific problem addressed in step (1) are reviewed and analysed in order to identify the solution that best fits the objectives of the project. In this step end user requirements are considered. In this project, the questionnaire shown in Appendix (A) was circulated to selected contractors and consultants firms in the UAE with fifteen questions aimed at identifying their immediate needs and also information about the available site equipment they have to be utilized in the project. The existing systems related to site safety were reviewed and it was concluded that this area still depends on manual approaches and lacks automation. The conducted survey showed that this project adds value compared to present methods used in existing sites.

Step 3 Business Analysis: The conducted survey section aimed at exploring the end users needs and aspirations resulted in identifying the following system requirements:

- Should be able to view different cameras.

- Should be able to accept stages.
- Should be able to view 3D model and BIM.
- Should be able to use image processing techniques to compare site photos.
- Should provide training views.

In this step, the solutions to the identified business problems were concluded. These solutions are required to address the following needs:

- The needs to enhance health and safety awareness.
- The needs to automate relevant hazards detection.
- The need to automate safety reports generation and output.

### 6.7 Construction Automata System Analysis

The possible solutions for the identified business problem were analysed in order to arrive at the best solution suitable to the objectives of the project. The end users needs obtained from the distributed questionnaire and the project's functional requirements were considered in order to identify the model goals and create a model that will achieve these goals in an efficient manner. An activity diagram was developed as shown in figure (6.3).

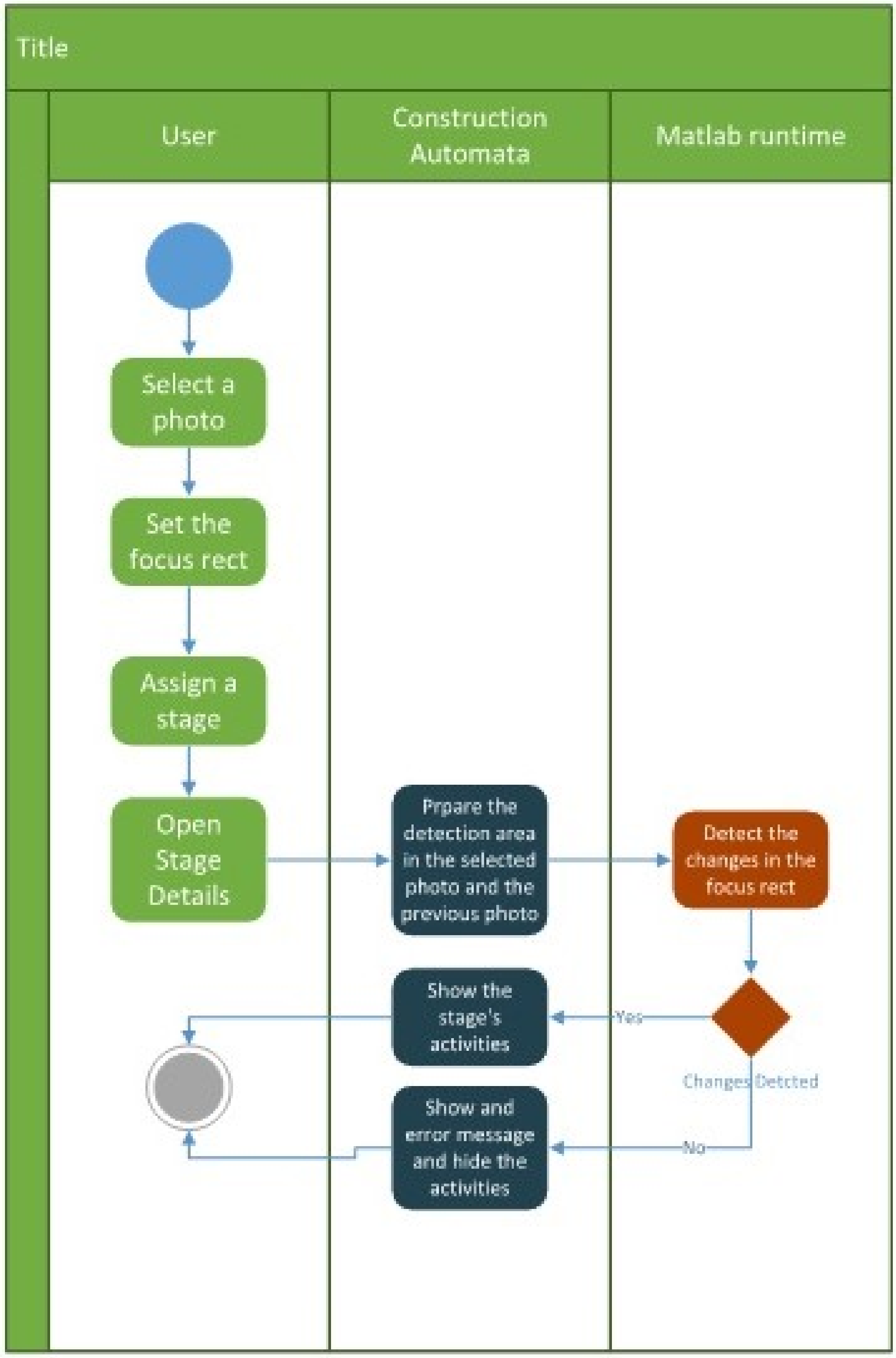



Figure (6.3): The model's activity diagram

The identified project's goals were refined to defined functions and operations of the intended applications using by UML (Unified Modelling Language) to analysis the proposed model. The UML provide slandered way to visualize the system have several tools. The selected tools used in this project were the structural tools and the behavioural tools.

The chosen structural tools were:

- (UC) use case which represent a set of functions performed by a system for a specific goal. The system users were classified as Admin users allowed to initialize the installation of a new project and Regular users which operate an installed account.

Table (6.1): System users

| | |
|---|---|
| **User ID:** | **SU01** |
| **Name:** | Admin |
| **Description:** | • This user has privileges of system administration.<br>• Create, modify and delete the projects<br>• Configure the system settings, Activities, Activities' documents and Training Videos.<br>• The admin has all the regular user privileges to operate the system |
| **User ID:** | **SU02** |
| **Name:** | Regular User |
| **Description:** | • This user can user all the operation features of the system for example, reviewing the projects details, assign the photos to their stages, review the stages' activities and review the training videos etc. |

The individual (UC) for both the Admin and Regular users are shown in Appendix (E).

(UCD) use case diagram was developed as shown in figure (6.4)

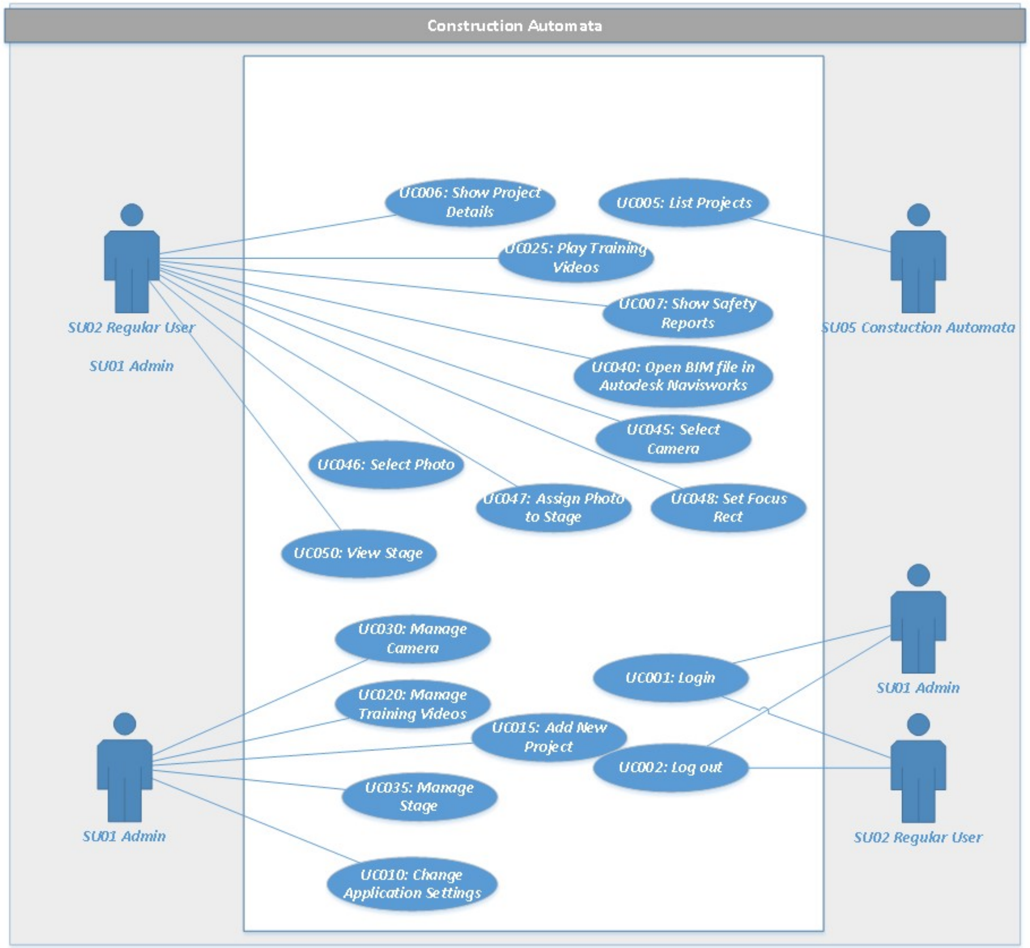



Figure (6.4): User case diagram

The chosen and developed behavioural tools which constitute the dynamic parts of UML models were the following:

1- A Class Diagram which includes the model's activities and the components of each activity was developed as shown in figure (6.5).

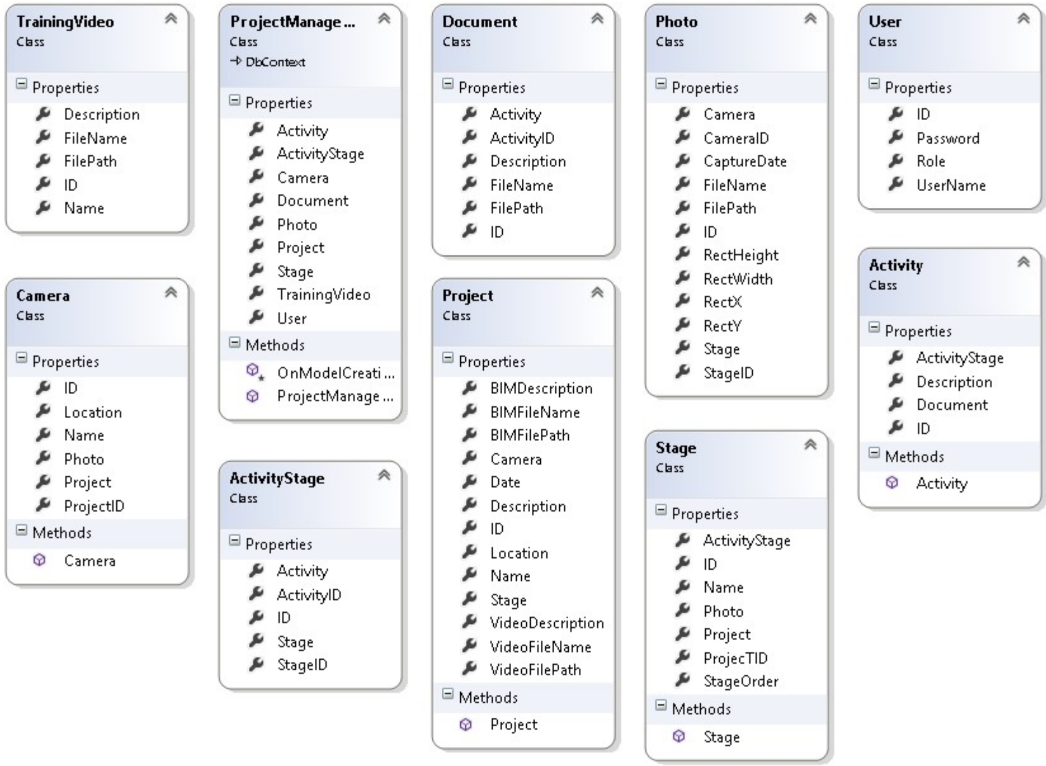



Figure (6.5): Class Diagrams

2- A component diagram was also generated as shown in figure (6.6):

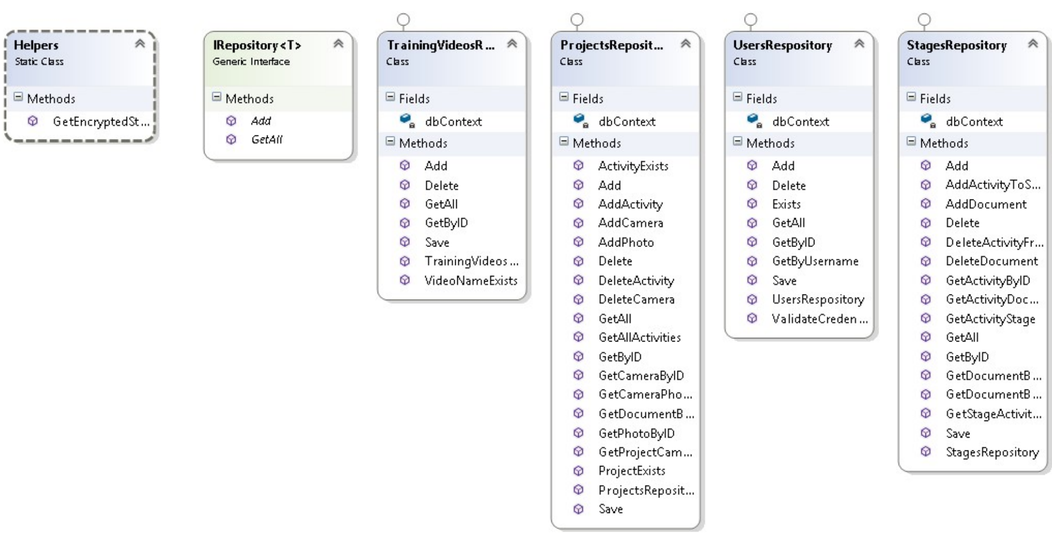



Figure (6.6): Component diagram

3- User interface layer forms were then generated as shown in figures (6.7) and (6.8):

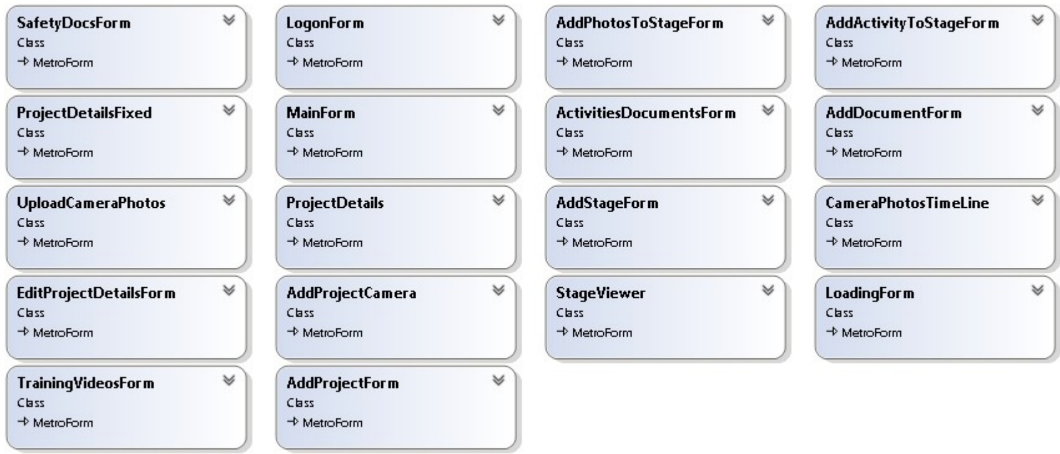



Figure (6.7): Interface layer forms

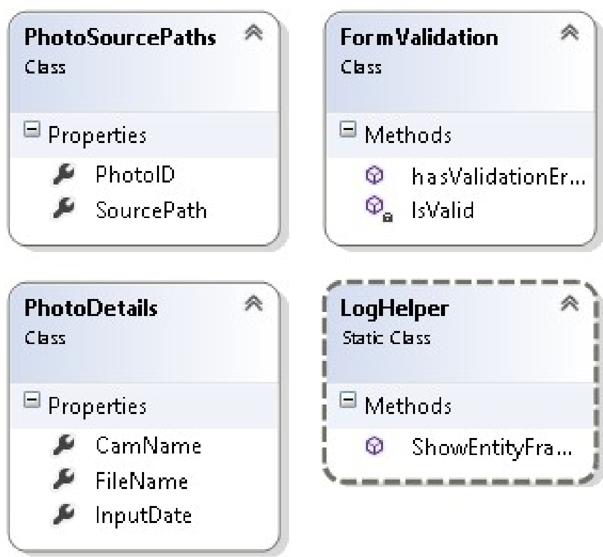



Figure (6.8): Helper class interface layer forms

## 6.8 Construction Automata System Design and Architectural

The desired features and operations of the developed system were described and after analysing the business requirements the following entities were defined:

- Project

- Stage
- Photo
- Camera
- Training videos
- User
- Documents
- Activity

The entity-relationship diagram (ERD) was then generated to define these entities, the attributes, and the relationship between entities as shown in figure (6.9).

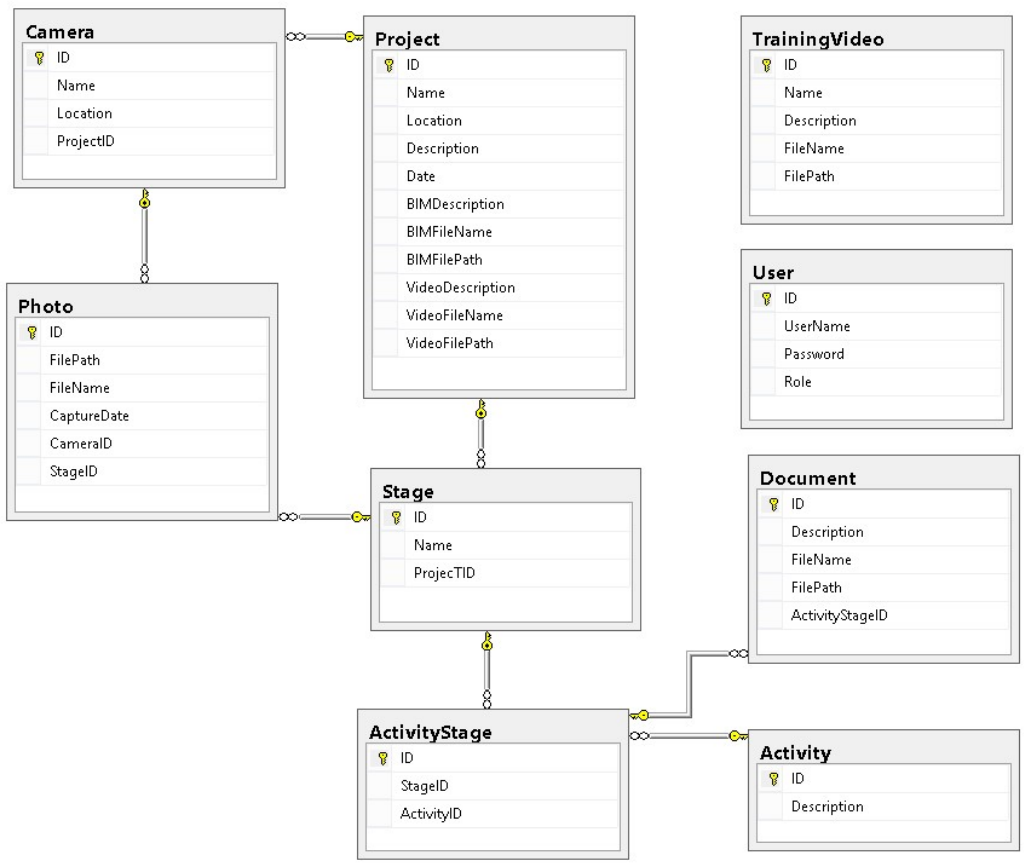



Figure (6.9): System design ERD

The next step was to develop the system architecture which is shown in figure (6.10):

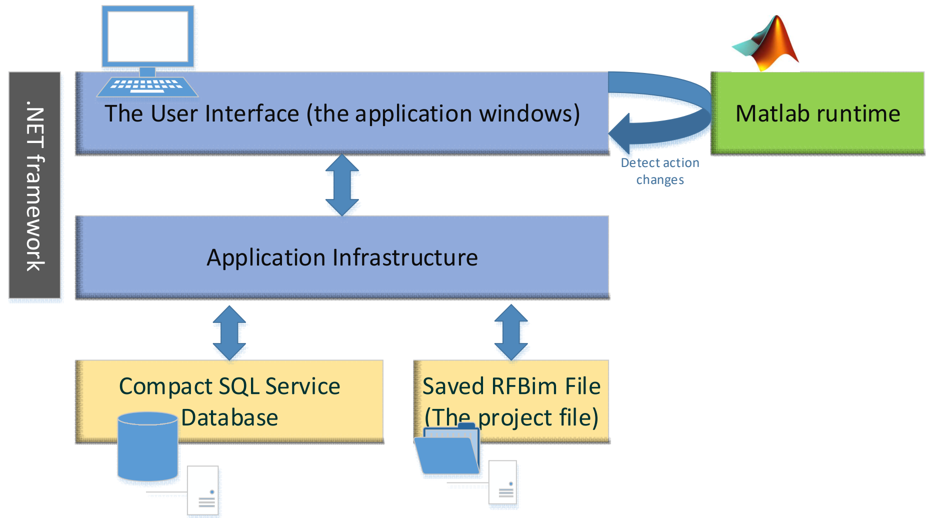



Figure (6.10): System architecture

The following actions to accomplish the system design were executed:

- A data base (DB) using SQL server was created depending on the ERD.
- The SQL server was used as RDBMS.
- A data table for each Entity was created in which each column represents an attribute.
- The relationships between the data tables were established as shown in the ERD
- As per business requirement the system needs to be integrated with Navisworks and MATLAB as shown in Figure (6.11).

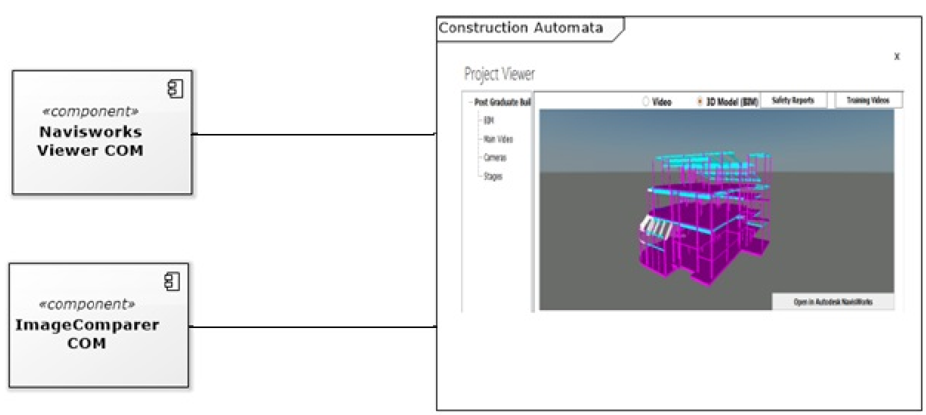



Figure (6.11): System integration with Navisworks and MATLAB

## 6.9 Construction Automata System Development

The platform used to develop the system is the Visual Studio 2012 using the programming language C#. The visual studio is an integrated development environment (IDE) from Microsoft. This IDE is mainly a tool used by the .NET developers to develop computer programs such as Microsoft Windows Desktop Applications, Web sites, Web applications and Web Services …etc. The Visual Studio supports many programming languages for instance Managed C++, C#.NET and Visual Basic.NET and also supports many techniques such as ASP.NET, Windows Forms and Windows Presentation Foundation.

C# (pronounced C-SHARP) is an OOP (Object-Oriented Programming Language). It aims at combining the computing power of C++ with the programming ease of Visual Basic. C# is based on C++ and contains features similar to those of Java. It is designed essentially to work with .NET platform.

The developed system (Construction Automata) is a portable solution and is a Windows Desktop Application, works as standalone application, and stores the data in a local file based SQL Server which saved locally in the system PC where the Construction Automata is installed. This makes it easy to install, portable, and does not need a server PC. In order to make use of its portable capability for any specific project, the operator can save the project as a JSON file (Java Script Object Notation) with an extension of RFBIM, which will help the operator to open this file on different PCs.

Construction Automata uses JSON to save the project files. The JSON Format was chosen for saving the Construction Automata Files because it is a lightweight format that is used for data interchanging. Furthermore, it is now the most well-known and readable notation. JSON is a minimal, readable format for structuring data. It is used primarily to transmit data between a server and web application, as an alternative to XML. Squarespace uses JSON to store and organize site content created with the CMS.

An example of RFBIM file for saving the camera details is shown in figure (6.12):

{
“$id”: “1”,
“Camera”: [
{
“$id”: “2”,
“Project”: {
“$ref”: “1”
},
“Photo”: [
{
“$id”: “3”,
“Camera”: {
“$ref”: “2”
},
“Stage”: null,
“ID”: “dd3e5a25-0f02-4bfb-a387-5268ef95ec68”,
“FilePath”:“E:\\Dev\\Rula\\AppData\\Project1\\Cameras\\East”,
“FileName”: “cam2east_2007_07_30_11_18.jpg”,
“CaptureDate”: “2007-07-30T11:18:00”,
“CameraID”: “1374ba9f-600b-4fcd-9770-5dcf0472b211”,
“StageID”: null,
“RectX”: null,
“RectY”: null,
“RectWidth”: null,
“RectHeight”: null
}
}

Figure (6.12): RFBIM file for saving camera details

Construction Automata has two main integration points with two systems (Autodesk Navisworks and MATLAB). The method used for communicating with these systems is achieved by:

1. Construction Automata has a built in Navisworks viewer, which enables the operator to run any Navisworks model inside the system user interface
2. Construction Automata has a feature to compare two stage's photos in order to detect the movements of the elements in the camera photos between the photos and show the related materials to the detected movements, this is done by using a MATLAB script and Construction Automata calls this program by passing the photos details and gets the result.

The methods used for integration with the external systems is achieved by using the technology COM (Component Object Model) which is a standard binary interface and enables an inter-interface communication. The COM object consists of group of exposed functions to be commonly used by the other systems; AutoCAD Navisworks exposes a group of functions as API (Application Programming Interface) as Client COM to be used by the host application.

MATLAB runtime compiler is used here to compile the MATLAB script (Image Comparer) and create a COM client library (DLL File) to be also hosted in Construction Automata

Construction Automata is the host of Navisworks Viewer COM and MATLAB runtime interpreter COM as shown in figure (6.13).

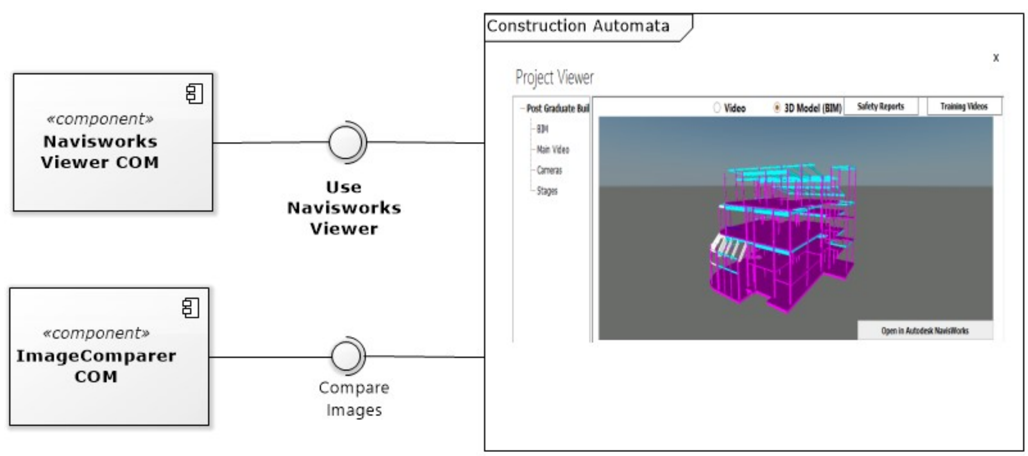



Figure (6.13): CA is the host of Navisworks Viewer COM and MATLAB

In order to compile a MATLAB script into COM Component, MATLAB provides a runtime compiler (MATLAB Runtime) which is a standalone set of shared libraries that enables the execution of compiled MATLAB applications or components on computers that do not have MATLAB installed. When used together, MATLAB, MATLAB Compiler, and the MATLAB Runtime enable the user to create and distribute numerical applications or software components quickly and securely.

The required steps to distribute the MATLAB script into com component are:

1. Examine the application to determine which MATLAB-based files to ship.
2. Generate interface functions for the target environment.
3. Invoke a target environment specific build tool to COM Component
4. Assemble the MATLAB files to create the COM library (DLL File)
5. Register the create COM library by using the windows command REGSVR32, this command registers the COM Library to be available in the .NET COM library to be reused by Visual Studio

The MATLAB command "function" is used to declare an interface function in order to wrap a MATLAB script in an interface function.

```
function [y1,...,yN] = myfun(x1,...,xM)
```

where

- y1, …, yN are the output parameters
- myfun is the function name
- x1, …, xM are the input parameters

Following figure (6.14) shows the text of the function "comparepics()" which used in ImageComparer.DLL.

This function is used in Construction Automata to compare the selected two photos.

```
function [f] = comparepics()
fileID = fopen(strcat(tempdir, 'input1.txt'));
text = textscan(fileID, '%s %s %d %d %d %d','Delimiter',',','TreatAsEmpty',{'NA','na'},'CommentStyle','//')
fclose(fileID);
celldisp(text)
i=imread(text{1}{1});
```

```
j=imread(text{2}{1});
i2=imcrop(i,[text{3} text{4} text{5} text{6}]);
j2=imcrop(j,[text{3} text{4} text{5} text{6}]);
figure, imshow (i2)
figure, imshow (j2)
%Extract R G and B for both images
r1=i2(:,:,1);
g2=i2(:,:,2);
b3=i2(:,:,3);
r11=j2(:,:,1);
g22=j2(:,:,2);
b33=j2(:,:,3);
%Mask the first image histogram on the second one
nr2 = histeq(r11,imhist(r1));
ng2 = histeq(g22,imhist(g2));
nb2 = histeq(b33,imhist(b3));
%Reform the second image
nj1(:,:,1)=nr2;
nj1(:,:,2)=ng2;
nj1(:,:,3)=nb2;
%Extract the red from both images
i3=i2(:,:,1);
j3=nj1(:,:,1);
%Subtract images
sub=j3-i3;
%figure, imshow (sub)
%Convert image inot binary with 70 threshold
sub1=sub>70;
%Dilatepixles
se1 = strel('disk',3);
sub2=imdilate(sub1,se1);
%Remove large objects
clrbw= bwareaopen(sub2,45);
%figure, imshow(clrbw)
```

```
%Dilate objects
se = strel('disk',5);
s=imdilate(clrbw,se);
%Remove large objects
c= bwareaopen(s,845);
%show final results
%figure, imshow (c)
%Show activity text on image
f= regionprops(c);
centroids = cat(1, f.Centroid);
[rr co]=size (centroids);
fileID = fopen(strcat(tempdir, 'output.txt'), 'w');
fprintf (fileID, '%d', rr);
fclose(fileID);
f = rr;
end
```

Figure (6.14): the text of the function "comparepics()"

Construction Automata is designed on N-tiers architecture. This architecture is also called Multitier or Multilayer architecture in the world of software engineering. N-tier application architecture provides a model by which developers can create flexible and reusable applications. By segregating an application into tiers, developers acquire the option of modifying or adding a specific layer, instead of reworking the entire application. Three-tier architecture is typically composed of a presentation tier, a domain logic tier, and a data storage tier as shown in Figure (6.15).

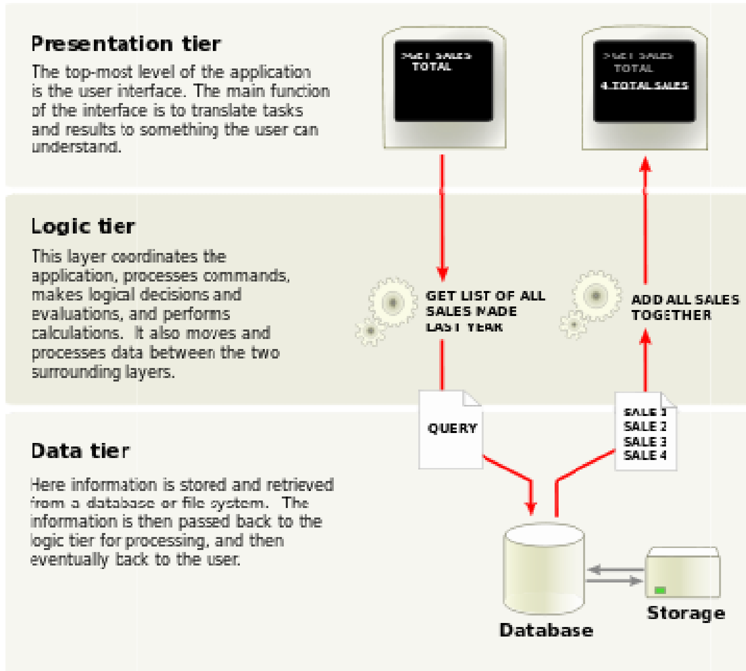



Figure (6.15): Construction Automata 3 tier architecture

The three layers are:

1- Data abstraction layer (DAL) which is a collection of all the functions to wrap all the database entities. These functions will be used in the BLL layer to access to the database entities and obtain the main database operations (Read data rows, write to data tables or Update data rows)
2- Business Logic Layer (BLL) which contains all the core functionality and the logic of the program for example (Calculations, storing and reading files, manipulating the elements etc.…). BLL is the middle layer between DAL and UI, and it is the bridge layer between the data in the database and the information presented in the user interface in both side being the reading from database to the user interface, and writing the data entered by the user into the database entities.
3- User interface Layer (UI) consists of all the pages of the program and handles all the commands in the pages (Textboxes, images, lists and buttons). This layer utilizes the function of the BLL to read and write the data in the DAL.

## 6.10 Summary

This chapter deals primarily with the development of a software knowledge management system model capable of analysing construction site digital images for the purpose of recognition of targeted work activities of interest. The model associates these activities with the relevant safety site instructions and training for the concerned labour force and issues the related safety reports.

These objectives were seen to fall under the general topic of knowledge management. In this chapter, a brief overview of the knowledge management concept was conducted together with its relation to and application in the construction industry. The building information model (BIM) was identified as an industry recognized information system which incorporates the project's design, construction, scheduling, and cost control in one 4D model. The work conducted throughout this project led to the development of a 4D model thus presenting the opportunity to incorporate the (BIM) facility. This incorporation was limited to providing for it within the development model without exploring its full potential being not the primary objective of this project.

The flow chart of the model was presented to illustrate the model's components and the relations between them.

The system development was based on the system development life cycle (SLDC) approach. The main models of the SDLC approach were reviewed in order to provide the background for selecting the waterfall model. The steps of this model and the development work done in relation to each of them was presented in this chapter.

# Chapter 7- Construction Automata Prototype and Operation

## 7.1 Introduction

In previous chapters, the steel structure erection activity was identified in chapter (3) as a suitable candidate for modelling in an attempt to reduce related site accidents through visual training. This training is most effective when delivered before embarking on their daily scheduled tasks and is associated to these daily tasks. A knowledge management system is required to integrate the 3D project's digital design with the project's time schedule in order to identify the daily work tasks and Construction Automata developed such a 4D system. The building information modelling (BIM) presented in chapter (6) is the knowledge management preferred system in the construction industry however it includes integrating further information packages with the 3D project's design such as specification, equipment vendor's information, inventories, project cost control …etc. The present shape of Construction Automata can be considered as a preliminary step in generation a fully-fledged (BIM) model and such model incorporating all the (BIM) can be identified as a future research topic. Field data in the form of acquired images was used for the progress tracking of building activities and generated safety reports can be checked and monitored.

This chapter attempts to develop a prototype software for the model (Construction Automata) whose integrated components are shown in figure (7.1), identify the requirements of the principle parts of this model and select the suitable software for their representation and incorporation. The operation of the developed model (Construction Automata) is described using the set of existing visual data base of a building constructed at the University of Edinburgh, together with a demonstration of its application by selecting specific activities, determining the associated hazards, selecting the safety training method related to these activities and generating relevant safety reports and forms.

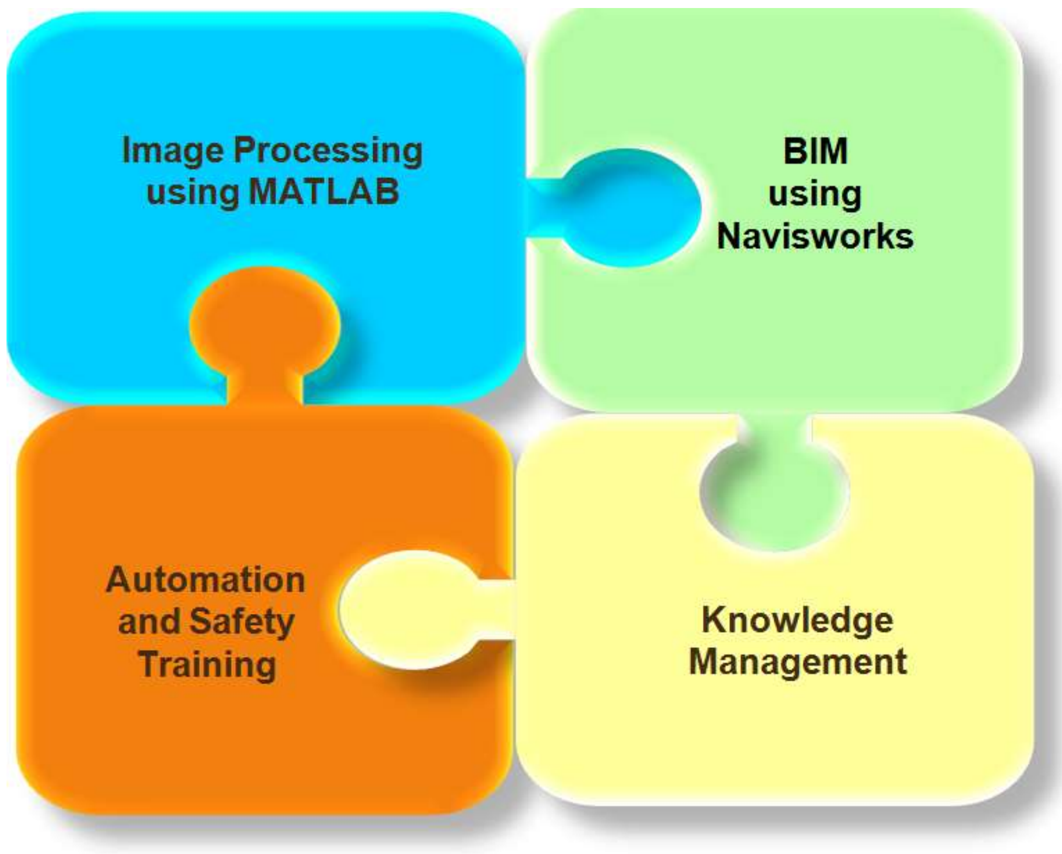



Figure (7.1) Construction Automata integrated components

## 7.2 Vision Base Training and Report Generation

Researchers have used accidents causation models in an attempt to understand the accidents caused by industrial applications. The objective behind the application of these models is to provide the means for accidents prevention programs in industrial activities. Accident prevention is defined as "An integrated program of a series of coordinated activities, targeted at the control of unsafe personal performance and unsafe mechanical conditions, and based on certain knowledge, attitudes, and abilities (Abdelhamid and Everett, 2000).

The driving force behind the research is incorporating safety in the design phase enhancing the construction site safety environment. The viability of this approach is related to the feasibility and implementation practicality regarding the nature of specific projects and is assessed by its impact resulting from the implementation of the concept (Gambatese, 2005).

In Chapter (2) the concept of design for construction safety (DfCS) was discussed. Designers generally do not include workers' safety in their designs due to the barriers facing this initiative, Toole et al. (2006**).** In order to incorporate workers' safety in the designs stage, designers complimented by construction managers should cooperate in the project's design. Furthermore, the ideas developed from this cooperation should be compiled and saved in a reference archive system which can be easily accessed by other designers. The creation of this body of knowledge and the development of its accessibility by the designing community is an important step towards addressing safety aspects during the design phase (Gambatese and Hinze, 1999).

Another important safety requirement is the existence of a safety plan which introduces the employees to the concept of occupational safety. This plan should be based on actual requirements and concentrates on practices leading to work safety. In order for such a plan to be properly evaluated, it should be followed by setting safety goals targets and a feedback procedure reporting on the performance of the participants. The implemented safe working practices recommended by the plan should be reviewed according to the received feedback to evaluate their effectiveness and long-term benefits. The plan should also be flexible to include the redefinition of principles resulting from desired conduct modelling, management's support, and behaviour sampling, (Vredenburgh, 2002).

Safety training allows participants to anticipate and recognize hazards by providing them with the necessary prediction tools. New employees should be enrolled in health and safety programs in order to enhance their safety awareness. This should be a continued effort of re-education and retraining to stay in pace with work and site developments.

Employees may not consider the possibility of injury resulting from decisions when conducting their activities. The required awareness program must not concentrate on operational safety alone, but must also highlight the possible harshness of injury in order to attract the attention to read warnings and act safely (Vredenburgh, 2002).

## 7.3 Model Framework overview

The principle steps in a project addressing health and safety in steel construction are:

- Subdividing the construction phase into major activities.

- Identifying the possible hazards associated with each activity

- Identifying the relevant hazard mitigation measures.

- Applying training programs to enhance the awareness of laborers.

- Store and retrieve safety reports in relation to site work activities as means of generating a project knowledge management system.

The manual implementation of these steps is gradually giving way to automated methods relying on the continued advances in design, image processing, and modelling software.

This study attempts to address the subject of Health and Safety in steel construction by utilizing the latest modelling software available to develop a dedicated modelling program that includes:

- Loading the site steel construction digital image frames and sorting them into construction stages.
- Using a 4D model to compare the design and scheduling stored information with the construction stage captured by each digital image frame.
- Identifying the possible hazards and their mitigation associated with the activity in each frame captured.
- Automatic storage and output of the relevant safety reports.
- Training of workers through selected videos representing the main expected hazards.

A building model prototype is generated by the continuous updating of the progress of each of the above activities. The foundation on which the system is built on is the database which includes time related digital images of the building components being monitored. An image processing operation helps to identify the work activity to which these images are related. The computerized image processing model can then be interfaced with the 4D model resulting from incorporating the 3D design and scheduling of the project. Having the 4D model and the site safety reports on the same platform provide a knowledge management system which can be expanded further to include other project information and activities.

## 7.4 The steel structure erection activities selected for modelling:

Compiling a comprehensive model which includes all steel structure construction activities is an evolving process in which the various activities can be added in stages once the foundations of the model are in place and it is tested relating to selected activities. This research project divided the site construction activities into three stages.

- Stage 1: Material unloading and material arrangement.

- Stage 2: Material arrangement including column erection and rafter erection.

- Stage 3: Construction finishing including roofing and flooring.

The purpose for stating the various stages and their requirements for selected components of the steel construction activity is to highlight the points which require attention in regards to site safety and hence be monitored or focused on during the review of site images data. The three stages also provide a logical segmentation of safety training material and videos.

### *7.4.1 Materials Unloading*

The construction materials can be in the form of an unprocessed raw material or a product that is put in such a form that allows and facilitates its transport and storage. Site preassembly processes turn some construction materials into semi-finished members that can be used in the construction process (Makwana and Pitroda, 2013).

Safe site materials handling requires special precautions and measures during unloading, checking, and storing such as:

- Materials involving hazards possibilities due to their weight, characteristics, or composition should be given special consideration in delivery, handling, and site storage allocation.

- Materials that are stored by stacking should be placed on firm ground easily accessible by loading and lifting machinery.

- New or uncommon materials should be provided with brochures outlining their safe usage in order that labour are provided with the necessary training.

Furthermore, materials are delivered to construction sites, either separately or on skids placed in containers, and are unloaded by suitable cranes. A recommended control measure is to take real pictures of the delivered materials prior to off-loading to document their condition on arrival to site.

### *7.4.2 Materials Arrangement*

The site location arrangement of the unloaded materials is important to avoid unnecessary movements resulting in possible damages and hazards. Materials should be placed close to their erection locations and conveniently stacked near the lifting position of the buildings areas. A site material arrangement plan should be prepared beforehand to ensure the ease of movement within the construction site.

The following guidelines are typical for proper storage and handling (Kirby's Building System, 2001).

- Columns are to be placed close to their anchor bolt position.
- Rafter members should be assembled to facilitate easy movement and assembly.
- Nested parts should be divided and blocked to allow for drainage of collected moisture in order to prevent corrosion, prior to erection.
- Small components (nuts, bolts, clips, fasteners etc.) are stored and arranged in a given assigned area to provide convenience for access to all parts of the building.
- Wall, roof paneling and other components, not used during the initial stages of steel erection, are placed in an exterior position from the work area and protected from the weather.

### *7.4.3 Steel Erection (Column and Rafter)*

Structural steel frame erection is one of the major activities in a construction project. This activity's pace is governed by the steel erector's crane which controls the rate of the erection process alongside other related activities. Steel erection can be considered as a timely process, whereby materials are delivered as needed to the site and installed as soon as possible (Tommelein and Weissenberger, 1999).

Furthermore, column erection is divided into the two stages of preparation and erection: (Kirby's Building System, 2001):

The following points should be considered during the preparation stage:

- Column materials are stored close to their position in the design, and cleaned.
- Three temporary anchor points are checked in order to safely anchor the column after being erected. The anchor points should be at a safe distance from working areas in order to avoid the interference of the temporary cable with other hanging materials.
- The crane's position and the weight being lifted should comply with the crane's manufacturer's specifications.

The erection requires that:

- Columns are lifted and positioned as per design.
- Once the columns are in right position, they are lowered on their casted anchor bolts and the anchor bolts' nuts are tightened.
- In order to maintain the column in their right position, temporary cables are connected to them and the chosen anchor points.

Thereafter erection is also divided into two stages of preparation and erection. The preparation stage requires: (Kirby's Building System, 2001)

- Scaffoldings installed allowing workers to perform connections between rafters and with columns.
- Three temporary anchor points are checked in order to safely anchor the rafters after being erected. Care is taken to ensure that the temporary anchor points are at a safe distance from working areas in order to avoid the interference of the temporary cable with other hanging materials.
- The crane's position and the weight being lifted should comply with the crane's manufacturer's specifications.

The erection stage requires that:

- The rafter is lifted up slightly is placed in the right position with respect to the crane.
- Rafter's position is adjusted for bolting by the workers standing on scaffolding.
- Once the rafter is in the right position, the workers will install temporary rod bracings and flange braces.
- The crane can only be released when all connecting bolts are tightened, and temporary bracings and flange braces are satisfactorily installed.

### 7.5 Health and safety hazards associated with the selected construction activities

The management process fundamental objective is to allocate its available resources to an optimal productive end. With the available resources of people, money, and time being limited, the managers need to allocate them in the most effective and efficient manner. The conservation of these resources means that the safety and health of employees is of a prime importance and managers should endeavour to lower any injury or hazard that may face their employees. In order to achieve this objective, the managers need to be aware of the required health and safety resources to ensure this outcome (O'Toole, 2002).

The Occupational Safety and Health Administration (OSHA) issues necessary requirements for the basic training of the construction workforce especially those involved around or with electricity. Individual employers bear the sole responsibility of compliance with these requirements. The employers vary in the way they conduct the required health and safety training. Some use structured materials and safety programs developed by media industry companies specialized in preparing relevant training programs. Other employers design and conduct training programs of their own. The important point in any training program is that it should satisfy the OSHA's requirements and is capable of adequately training each participant to accomplish his site's job safely (Zhao et al., 2009).

The role of the management has the highest impact on site injury rates, O'Toole (2002) The efforts focusing on key management processes e.g. OSHA's Voluntary

Protection Plan, have demonstrated that the methodical management of safety and health processes results in lower injury rates and higher productivity.

A study conducted at eight manufacturing sites to evaluate the impact of employee's participation showed that by encouraging employees to get involved in the safety process resulted in lower incidents, lower lost time injuries, and lower injury severity rates over time (O'Toole, 2002).

The hazards associated with any of the chosen activities for modeling are very many and identifying them is the first step in their recognition in the image processing process. Furthermore, the intended site training material should be tailored to address them. Due to the large number of activity's hazards, the steel erection activity is chosen being the one of principle interest in this research project. The main steel erection hazards and their mitigating actions are:

- Transportation of steel components from yard to site: The personnel at risk are workers and helpers. Minimizing this risk is by third party inspection of lifting equipment and lifting gears verified by site supervisor prior to commencement of works.

- Assembling Installation / erection of steel components: The personnel at-risk are steel erectors, helpers, and crane operator. Minimizing this risk is by the equipment operator being authorized and has license to operate that equipment, conducting safety induction courses, and implementation of prevention maintenance programs

- Cutting Work: The personnel at risk are steel erectors, helpers, and crane operator. Minimizing this risk is by storing hazardous equipment such as gas cylinders in shaded storage areas and providing them with proper regulator and flash back arrestor. Also, training of related personnel by conducting daily tool box meeting.

- Welding Works: The personnel at risk are steel erectors, helpers, and another co-worker. Minimizing this risk is by using the suitable welding machine, inspecting and calibrating machinery prior to its use.

- Tightening the Bolts: The personnel at risk are steel erectors, helpers, and other co-workers. Minimizing this risk is by using safety harness, inspection of working platforms, and placing safety sign boards.

- General housekeeping: The personnel at risk are steel erectors, helpers, and other co-workers. Minimizing this risk is by returning tools and equipment to their proper place and clean the work area.

- Falling from Height: The personnel at risk are steel erectors, helpers, and another co-worker. Minimizing this risk is by ensuring close job supervision and providing adequate working scaffolding.

- Fall of Material during Lifting: The personnel at risk are steel erectors, helpers, and another co-worker. Minimizing this risk is by crane inspection and ensuring lifting tackles used are in good condition with valid test certificate.

- Failure of Lifting Tackles: The personnel at risk are steel erectors, helpers, other workers. Minimizing this risk is by the use of approved third party certified tools and tackles and visual inspection of the tackles prior to use.

- Failure of Crane: The personnel at risk are steel erectors, lifting supervisor, rigger, and crane operator. Minimizing this risk is by using cranes with third party certificate operated by competent operators, conducting preventive maintenance and maintaining its records, avoiding of overloading and respecting load limits, and insuring sufficient illumination during working at night.

- Hitting other structure: The personnel at risk are steel erectors, lifting supervisors, riggers, and crane operators. Minimizing this risk is by providing tag line to the material to be lifted, and no load shall be lifted before the appropriate clearance is obtained.

## 7.6 Displaying the selected activities in an advanced visualization tool

Construction visualization utilizing 3D technologies is becoming a very popular technique widely used in the planning of construction projects during the past fifteen years. The significant advantages and possibilities of the emerging visualization techniques are becoming increasingly evident to researchers and professionals working in this field. The modern construction industry is becoming more and more familiar with 3D modelling and is utilizing them to enhance the design and construction control of projects (Rwamamara, 2010).

Recent technological advances in the fields of information, sensing, visualization, and spatial analysis technologies generated new forms of spatial knowledge of construction job site conditions. The application of these technologies combined with effective management practices, provides a significant opportunity to decrease job site and operational safety risks. Zhou et al. (2012) presented a summary of the related approaches and technologies and their foreseen features. The basic idea behind these technical approaches is the fact that construction site safety risks can be detected by the observation, modelling, and tracking of 3D boundaries around foreseeable hazardous zones. These hazard prone areas are then classified and separated from the other active construction workspace. Video rate range imaging technique renders itself as a suitable method for fast detection, modelling, and tracking of the position of static and moving obstructions. These activities are performed from a stationary or moving sensor platform. Video laser range scanning technology is used for obstacle avoidance systems, to quickly detect, model, and track the position of stationary and moving obstacles (Zhou et al., 2012).

Due to the importance of training in maintaining an acceptable level of job safety on construction sites, some researchers have embarked on discussing several methods to stimulate safety trainees' interest in appreciating the value of safety training. One such new method is to facilitate teaching by using Virtual Reality (VR) techniques. VR simulation can be used for the adoption of comprehensive knowledge management system since it includes all of the elements required for active learning. The simulation utilizing this VR feature is found to be feasible in safety training and for the assessment of construction workers' learning results (Zdenek et al., 2013).

## 7.7 Construction site safety reports

A safety report can be defined as a written document prepared by the operators at the site and raised to the competent authority in order to demonstrate that all the necessary measures have been taken to avoid major mishaps and limit their consequences on the personnel and the surroundings. Special, systematic, and careful attention should be given in the case of manufacturing, storing and using dangerous substances when generating safety reports by operators. These reports constitute the base of a knowledge management system which can assist in the future in identifying any required improvements to the management systems, plant, equipment, or safety procedures. They also serve in reducing the risk of occurrence of major accidents.

The Operators of newly constructed sites have to prepare their construction safety reports and operational safety report prior to the commencement of the construction or operation of the project while the operators of existing operational projects can use reports previously submitted.

Safety reports should be revised at least once every five years. They should also be revised when any changes take place in the project that could significantly affect the safety of the site. The operator must report back to the competent authority of the project any changes made to the safety report resulting from these reviews.

### *7.7.1 Health and Safety Report*

Operating the project's site safely is the legal obligation of the operator. The operator has to control the risks caused by the operations on the project's site and mitigate their consequences on workers, people living in the site's vicinity, and the environment. The competent authority duty is to assess whether the safety report has provided sufficient evidence that the site operator is conducting his work in strict accordance to health and safety guidelines and regulations in place. The safety report must include:

- A major accidents prevention policy;
- A management system for implementing that policy;
- A detailed description of envisaged major accidents, their occurrence likelihood, and their potential consequences;
- The measures to be adopted such as safe plant or safe operating procedures in order to prevent major accidents;

- The design and construction safety precautions information built into plant and equipment;
- Details of containment measures such as fire-fighting or relief systems utilized to constraint the outcome of any major accident that may occur; and,
- Site emergency plan comprehensive information which is also used by the local authority in the preparation of the off-site emergency plan.

The report should also include technical data regarding the possibility of the occurrence of major accidents and their probable consequences regarding the workforce, the public, and the environment. The description of accidents' consequences demonstrates that the operators have evaluated the associated risks and the envisaged control actions are suitable to mitigate major accidents. It should be noted that the possibility of occurrence of a major accident could be insignificant when it is compared with day-to-day health and safety risks however their importance is derived from their impact (Health and Safety Executive, 2013).

### *7.7.2 Site construction activities and hazards identification forms*

As seen in the previous articles of this chapter and in the steel construction industry, it is highly important to list the activities involved in order to avoid the safety risks that are associated with these activities. In this respect construction companies need to prepare and make available a general form to state these nominated activities together with their general description. An example of a simplified form is shown in figure (7.2).

| Job Location | Analyst | Date |
|---|---|---|
| Metal Shop | Job Safety | |

Task Description:

Worker reaches into metal box to the right of the machine, grasps a 15-pound casting and carries it to grinding wheel. Worker grinds 20 to 30 castings per hour.

Hazard Description:

Castings have sharp burrs and edges that can cause severe lacerations.

Hazard Controls:

1. Remove castings from the box and place them on a table next to the grinder.
2. Wear steel-toe shoes with arch protection.
3. Change protective gloves that allow a better grip.

4. Use a device to pick up casting.

Figure (7.2): Job hazard analysis form (OSHA, 2002)

The detailed forms are generally arranged in two stages:

The first stage contains the essential descriptions including the activity name, the actual time and date of execution, the actual location, and the risk evaluation of the activity.

The second stage consists of the general queries about the chosen activity, such as:

- Activity description.
- How often the activity is carried out.
- The time span of activity execution.
- The number of persons involved in the activity at any given time and in total.
- The sequence of performing the activity within the project's schedule.
- Are the environment conditions suitable for the activity environment?
- The equipment/installation/resources are used in the activity.
- What are the equipment maintenance requirements?
- What written procedures/instructions are available?
- What training/info is given?
- Description of the control measure in place for safety assessment.
- Foreseeable hazards Identification

## 7.8 Construction Automata operation

The computerized model of Construction Automata is a piece of original coding compiled for the purpose of this research project not based on any existing commercial software system. The flow chart of this model was presented in section (6.5.1) of this thesis. The main program, its modules interconnections, and the software languages used in the development are shown in figure (7.3).

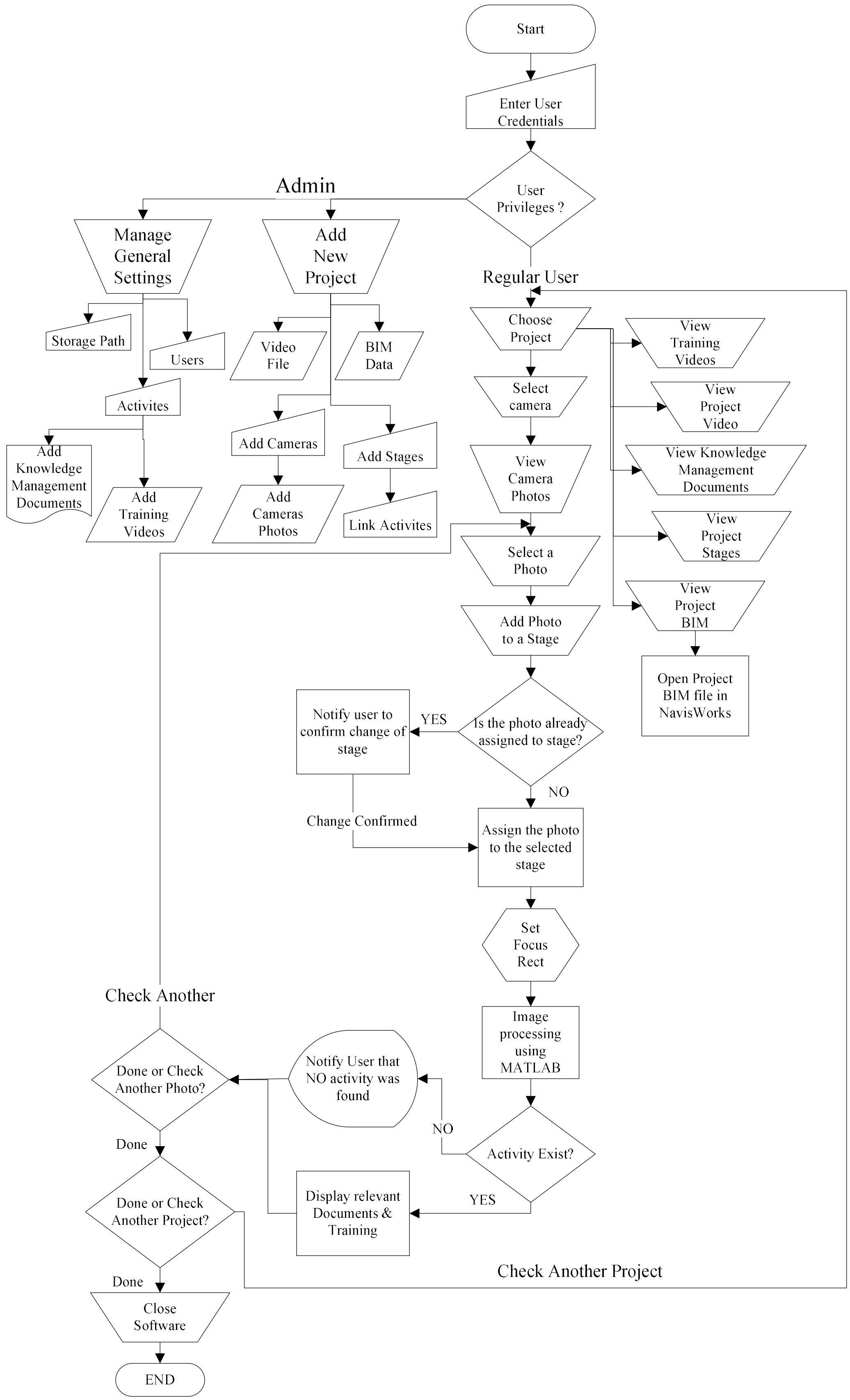



Figure (7.3): Construction Automata modules

All the modules were specifically developed using the suitable programming languages for each as shown in figure (7.2). Although this approach consumed considerable time and effort in getting acquainted with various programming languages and having to go through the checks and tests required to generate each package and ensure its compatibility with the others in the main program, however it eliminated the need to verify the suitability of an alternative adjusted existing package not originally related to the target model.

The developed model has an administration mode and a user mode. The Administration mode relates to the initial and basic settings for a new project while the Regular user mode is for editing the general user accounts of an installed project. The following articles present a step by step approach to the steps required to start and operate each mode. The illustrations are actual computer screen images of the model's operating steps.

### *7.8.1 Administrator Mode*

As the software initialize the login window will pop up as shown in figure (7.4) asking for user credentials, for the first-time initial settings use the following can be used Username: ***Admin*** Password: ***123456.***

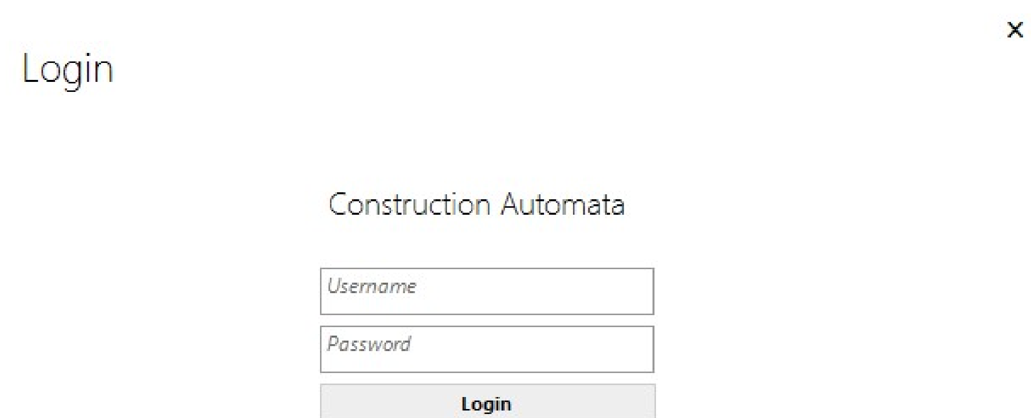



Figure (7.4): User credentials

Using a valid Administrator user credentials will allow the operation of Construction Automata in Administrator mode, the main window of the software will be as shown in figure (7.5) below.


Figure (7.5): software main window

Administrator user can start setting and adding the different details of the project, and its database. Clicking on “**Add New Project**” button will open the Add New Project dialog box as shown in figure (7.6) below.


Figure (7.6): Add new project window

Add New Project dialog box will require all the fields to be filled with relevant information about the project such as project Name, and Location, Description. A suitable path will need to be added to link to both project video file and BIM file with field available to describe each of them as shown in figure (7.7) below.

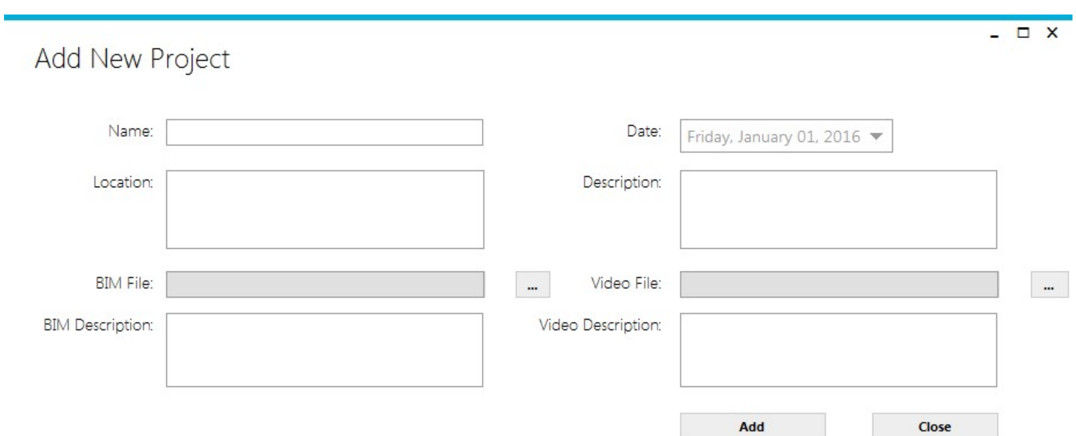



Figure (7.7): Project information

Filled example of the **Add** New Project dialog box is shown in figure (7.8) below with all the relevant information.

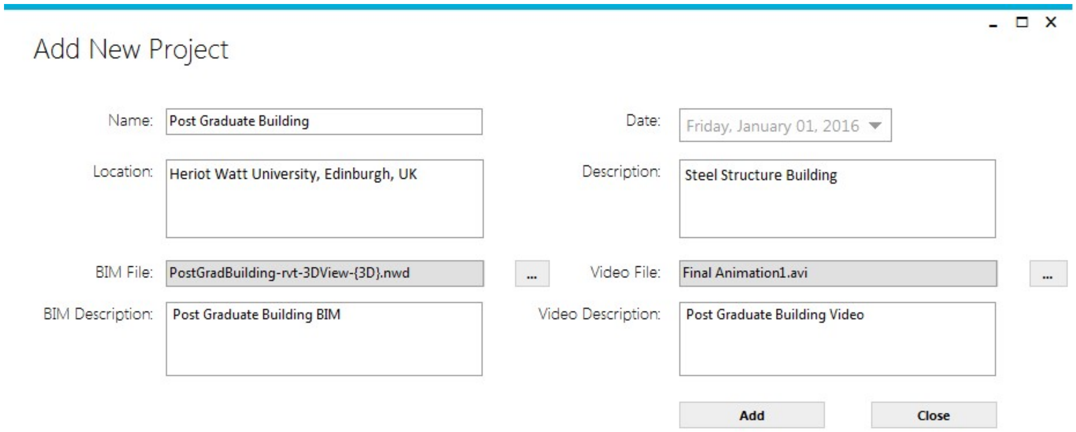



Figure (7.8): Filled project information form

After successful addition of new project, the details of the project will be available on the main window as shown in figure (7.9) below.

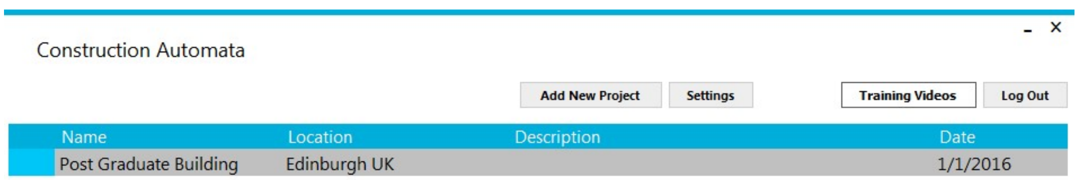
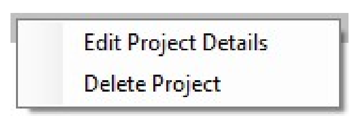



Figure (7.9): Project details

Using right click on any of the projects on the list, sub menu will appear with two options




Choosing "**Edit Project details**" which will open a separate window similar to the "**Add new Project"** to edit all the relevant project details, and files as shown in figure (7.10) below.

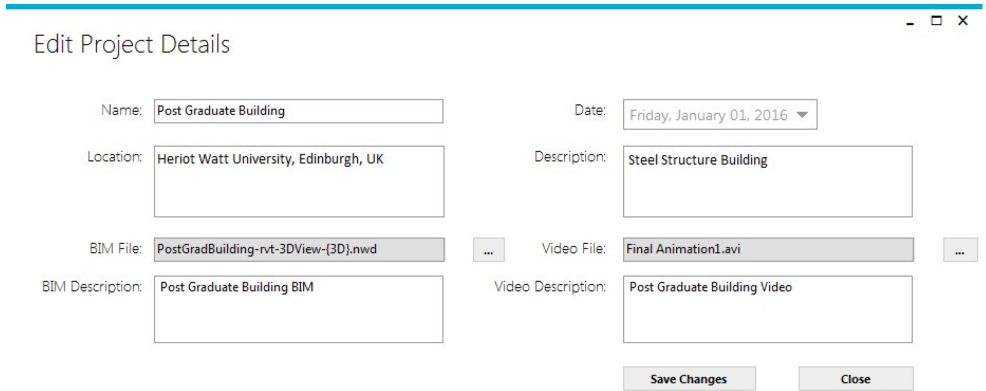



Figure (7.10): Edit project details window

**Choosing "Delete"** option will delete the project and all relevant information and confirmation will be required. After confirming the delete action, details of the deleted project will be permanently deleted from the software, this does not apply to externally linked files, such as BIM, and Video.

Clicking on the setting button shown in figure (7.11) will open the "**Setting**" menu which can be used to modify the different setting of the software such as "Storage Path" for all permanent and temporary files required for the operation of the software, and Browse button is available to locate a suitable part for the same as shown in figure (7.11).

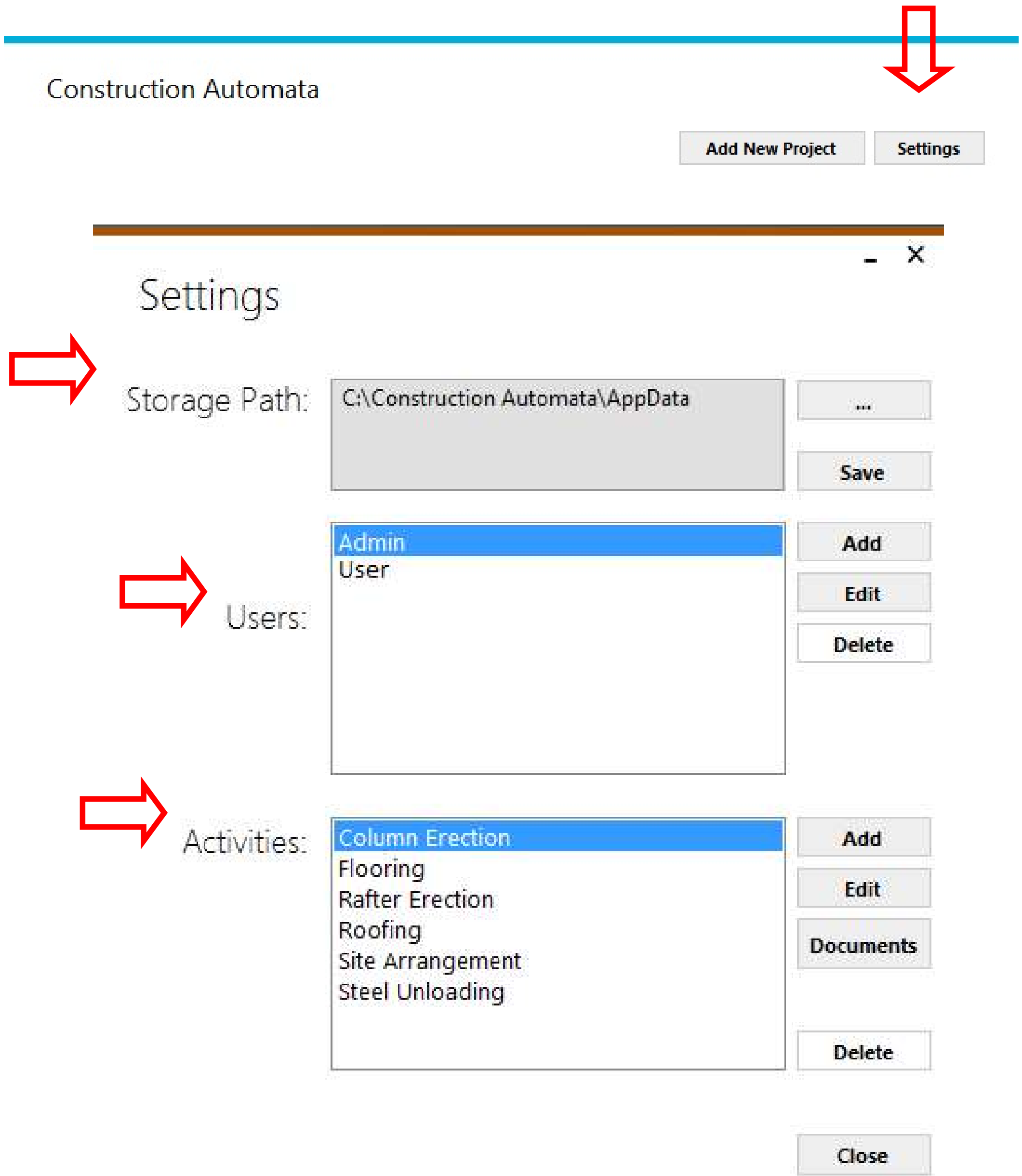



Figure (7.11): Choosing different settings

User data can be modified in the Settings window shown in figure (7.11) above as well. New users can be added by clicking on the "**Add**" button will activate a popup window with fields for the login cardinals of the new user. One of two types of users can be selected "**Admin**" for administrator privileges or "**Regular**" for normal or limited user privileges "**Add New User**" window is shown in figure (7.12) below. By selecting any of the listed users, and clicking on "**Edit**" button similar window will popup which allow editing

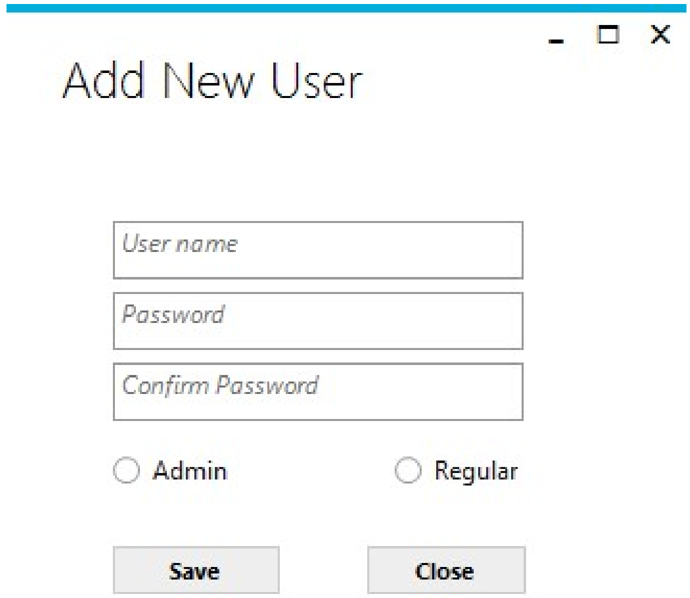



Figure (7.12): Selecting user type

Activities section of the "**Settings**" window shown in figure (7.13) allow the management of the complete activities within any given project adding activates, and relevant documentation is also possible by using the "**Add**" and "**Documents**" buttons respectively.

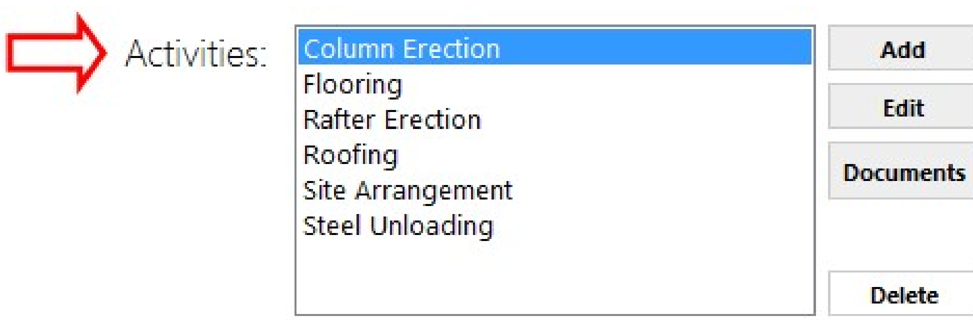



Figure (7.13): Activity setting window

Clicking on the "Add" Button in figure (7.13) will popup Add Activity window which contains one field to describe the new activity as shown in figure (7.14).

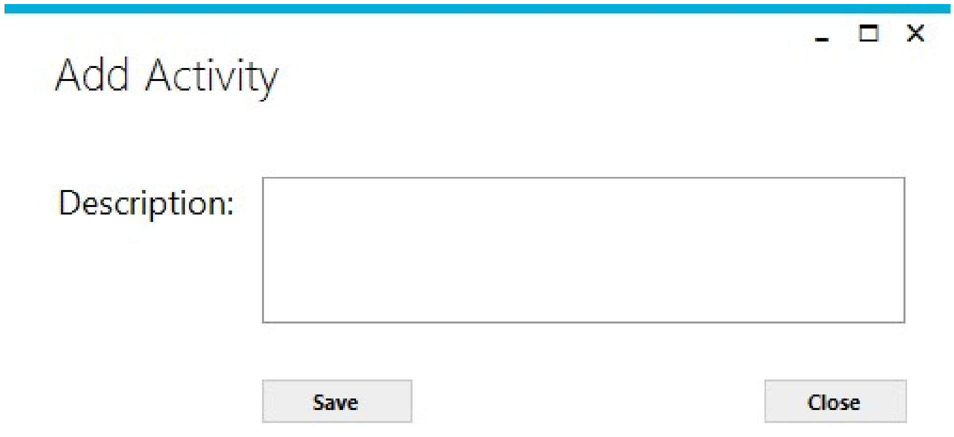



Figure (7.14): Add activity window

Clicking on "**Documents**" button shown in figure (7.13) is possible only after selecting an activity from the list, this will allow the addition of relevant documents to that specific activity as shown in figure (7.15).

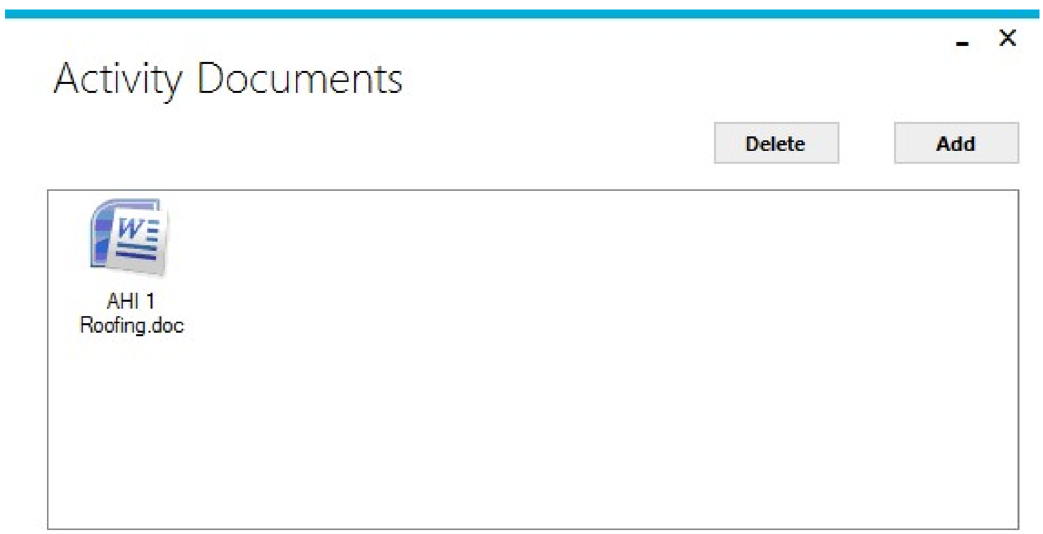



Figure (7.15): Activity document window

Double clicking on an any project from the list will open the project viewer window shown in figure (7.16)which has all the relevant information about the project, the left side of the screen has a directory tree with the project name on top, and four sub division below, the first two are to view the BIM file and video files, the third one marked as "Cameras" is to add, remove, and edit project cameras, their locations, and photos, while the fourth tab covers stages of the projects which can be set from the administrator account to be used by regular users.

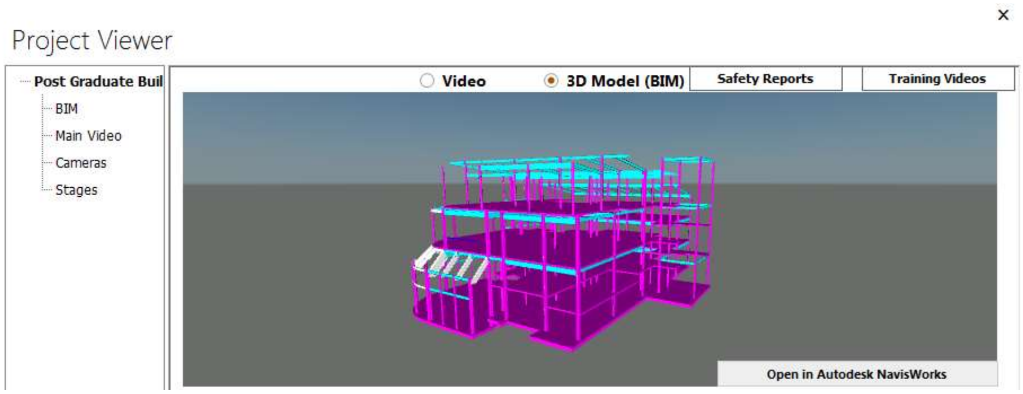



Figure (7.16): The project viewer window

If the "**Cameras**" tab is selected, administrator can add and remove cameras from the project, then with any camera selected photos can be added to that specific camera as shown in figure (7.17).

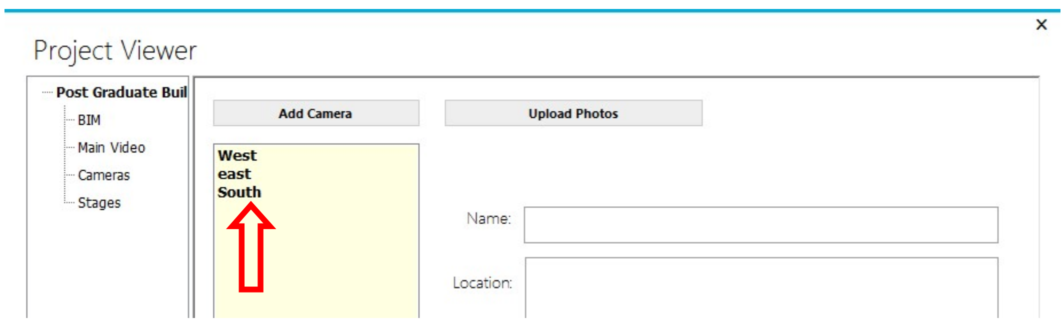



Figure (7.17): Adding or removing of cameras

While selecting stages tab allow adding, removing, and editing of the project stages. The activates within the stage can be modified with any individual stage being selected as shown in figure (7.18).

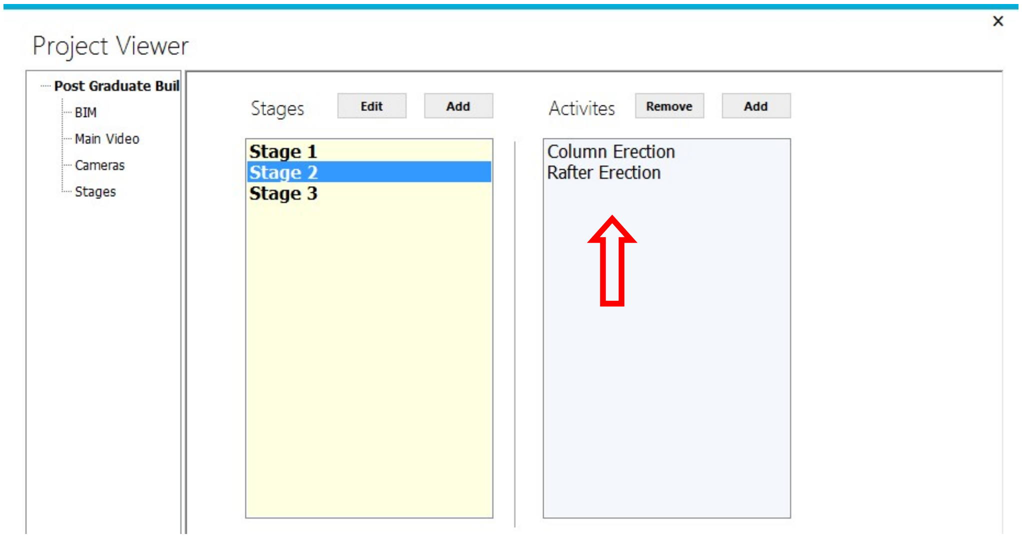



Figure (7.18): Stage selection window

### *7.8.2 Regular User Mode*

Using login cardinals of regular user will operate the software in user mode which has different set of privileges, this section will describe the different features and operation user can perform while in this mode. To login in user mode there are no default username and password, this mode can be used only after setting login cardinals by system administrator as shown in figure (7.19).

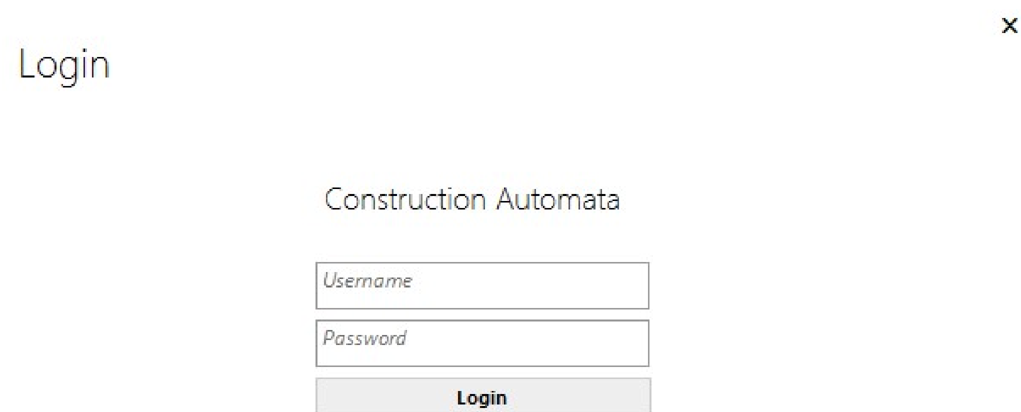



Figure (7.19): User mode login

After successful login in user account software home page will open with list of projects names, location, description, and date as in figure (7.20).


Figure (7.20): Projects list window

Double click on any of the listed projects will open the "**Project Viewer**" window shown in figure (7.21) which is divided into four parts:

1- List of the different project components, and information.

2- User can select between review of project video or 3D Model (BIM).

3- Selection of camera view with list of uploaded photos thumbnails.

4- Image preview of any photo selected from 3 above, and selection of stages.

Details of the above listed areas are shown in the following screenshot.

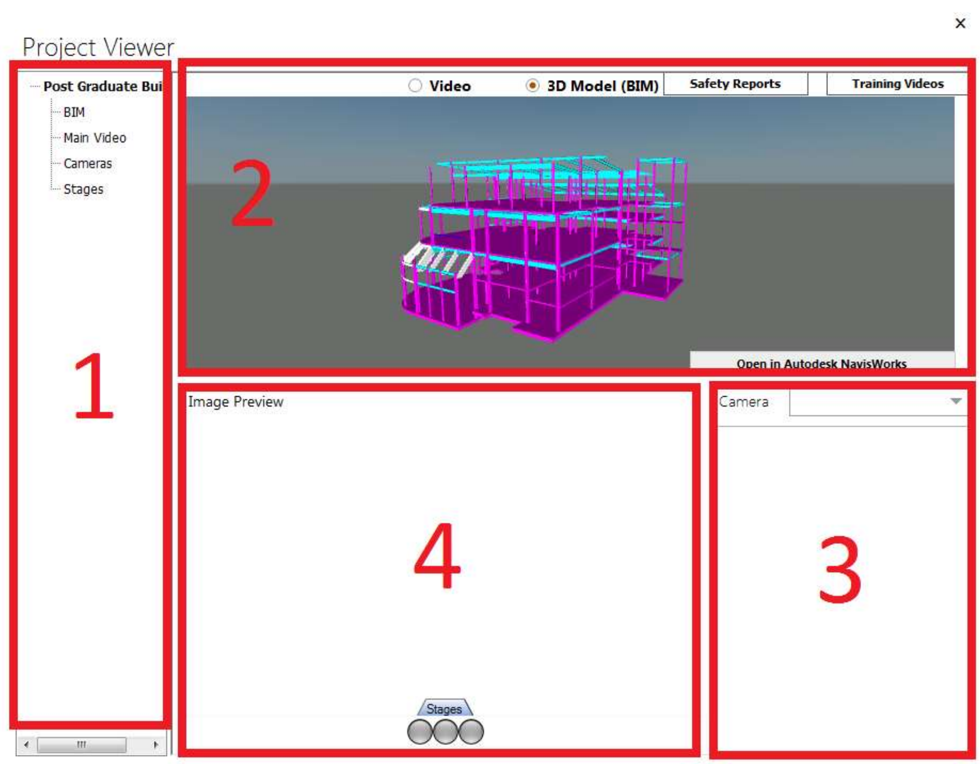



Figure (7.21): project viewer window

By clicking on “**BIM**” from the project component located in area-1 the user can view the allocated project BIM file preview, file description, and can also chose to open it in Autodesk Navisworks for additional information as shown in figure (7.22).

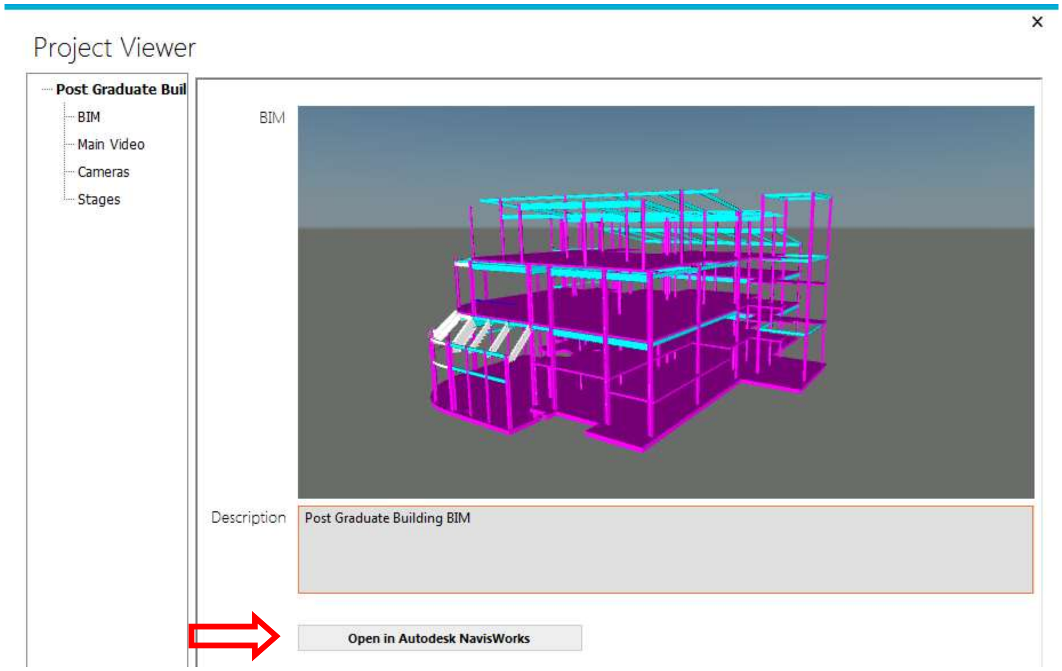



Figure (7.22): Project open selection window

The main video tab contains the project main video. The user can play the video in order to obtain better understanding regarding the project nature, and flow of work as shown in figure (7.23).

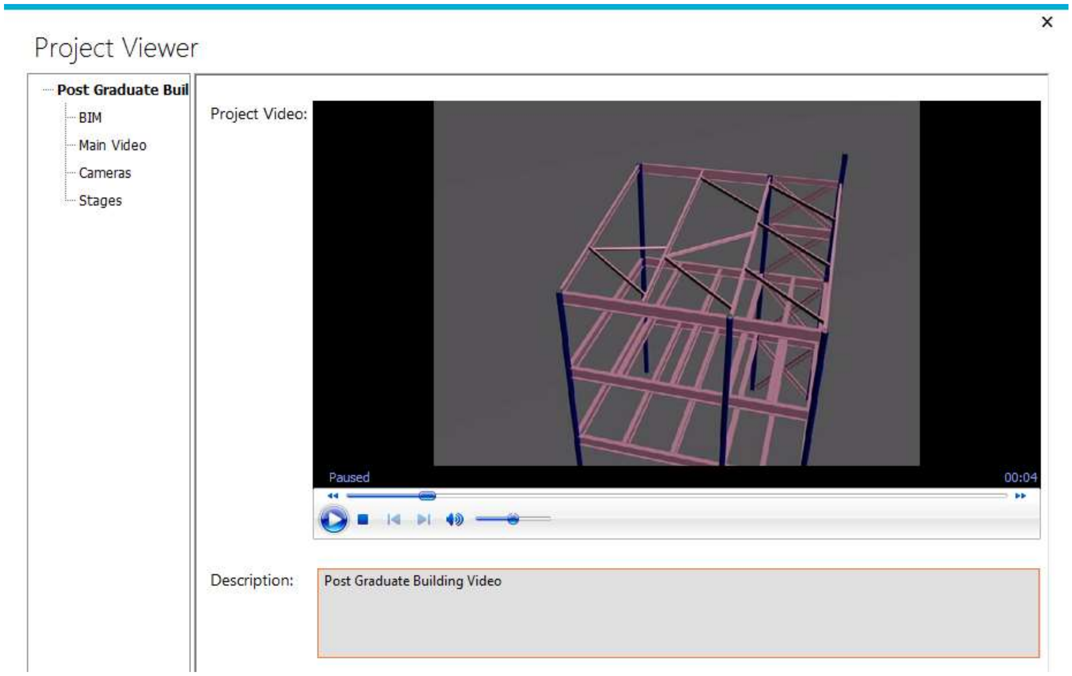



Figure (7.23): Opening of training video option

Both above features can be accessed from the main screen of "**Project Viewer**" area-2 by using the selection available in there to view the 3D model, open BIM in Autodesk Navisworks, or play the project video. as shown in figure (7.24).

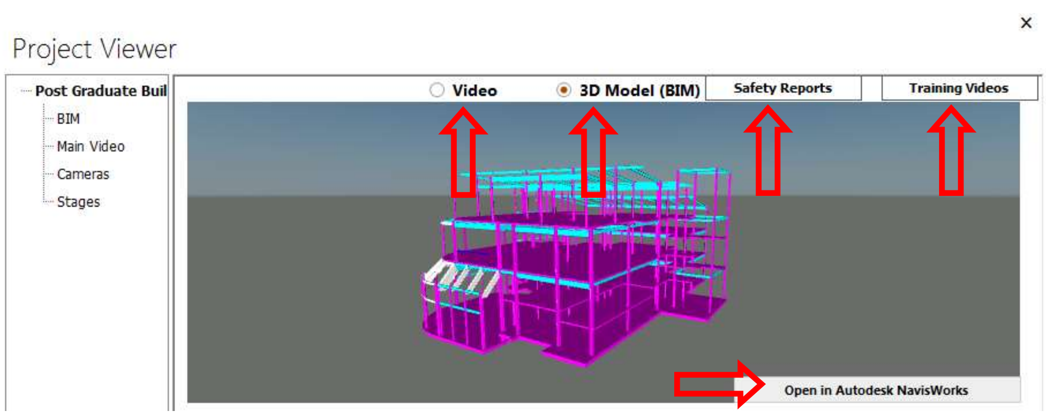



Figure (7.24): Features selection

The user can select any of the training videos listed, either for pre-review or for training of the site team as shown in figure (7.25).

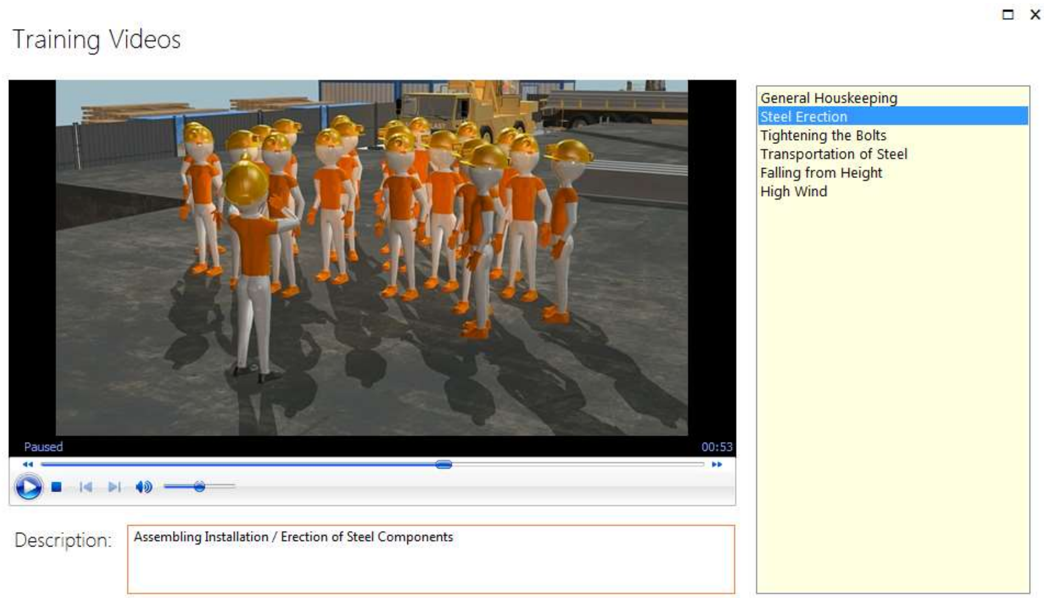



Figure (7.25): Training video selection

Safety Reports tab shown in figure (7.26) can be considered as knowledge management documentation system, this feature allows the user to report any safety related information like safety violation or accidents, this feature support the process of knowledge management such as monitoring, sharing and locating knowledge.

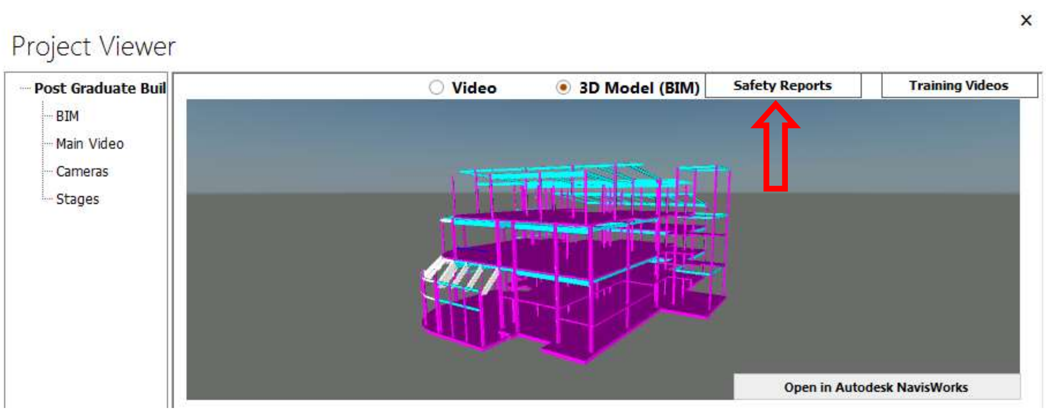



Figure (7.26): Features selection

All the project's related knowledge management documents and reports can be can be reviewed as shown in figure (7.27).

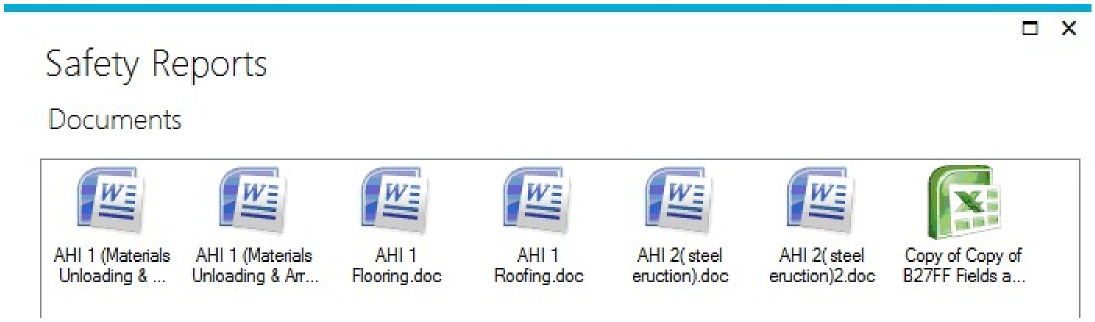



Figure (7.27): Safety report selection

Cameras tab of the project components contains information about the cameras available in the project and their location as shown in figure (7.28).

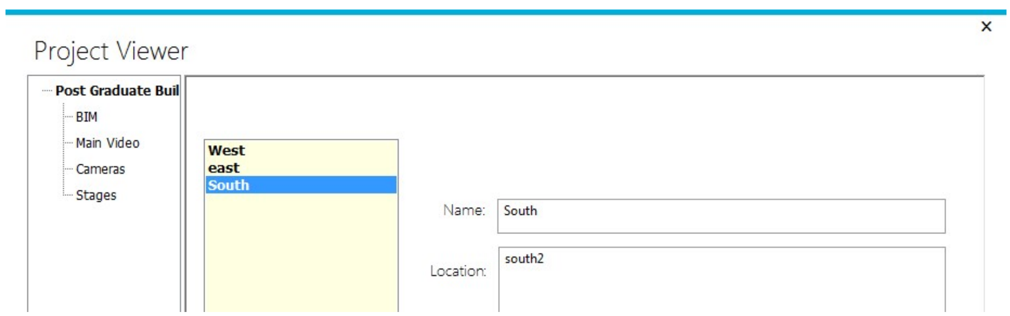



Figure (7.28): Camera location selection

Stages tab contains information about the different stages of the project, selecting any of the listed stages will view the respective activates within that stage as seen in figure (7.29).

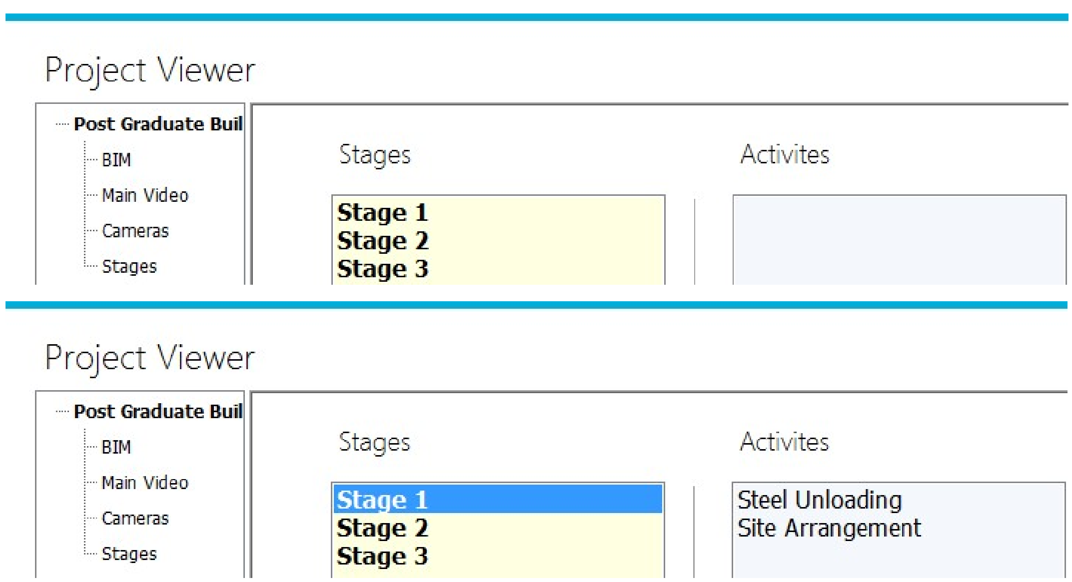



Figure (7.29): Stage and activity selection windows

Clicking on any of the tabs at the left will take the user to the relevant information similarly clicking on the project name on the top of the other tabs will get the user back to the main screen where the project video and 3D model are shown.

From the "**Project Viewer**" window the user can select from the drop-down menu any of the cameras listed in the project. After selection, thumbnails of all the uploaded photos will appear listed based on date and the time in which the photos were taken, next to each thumbnail time and date details are available so the user can scroll up or down to get to the target date. Clicking any of the thumbnails will enlarge it in the "**Image Preview**" area. Below the image preview there are the stage selection buttons. For any image selected and by hovering with the mouse pointer over the stage selection circular buttons, this will enlarge them in an animated effect so the user can select the appropriate stage for the photo being viewed. Selecting the right stage will change the button colour to green and the stage selection will be saved for the specific photo unless changed by the user at later time as shown in figure (7.30).

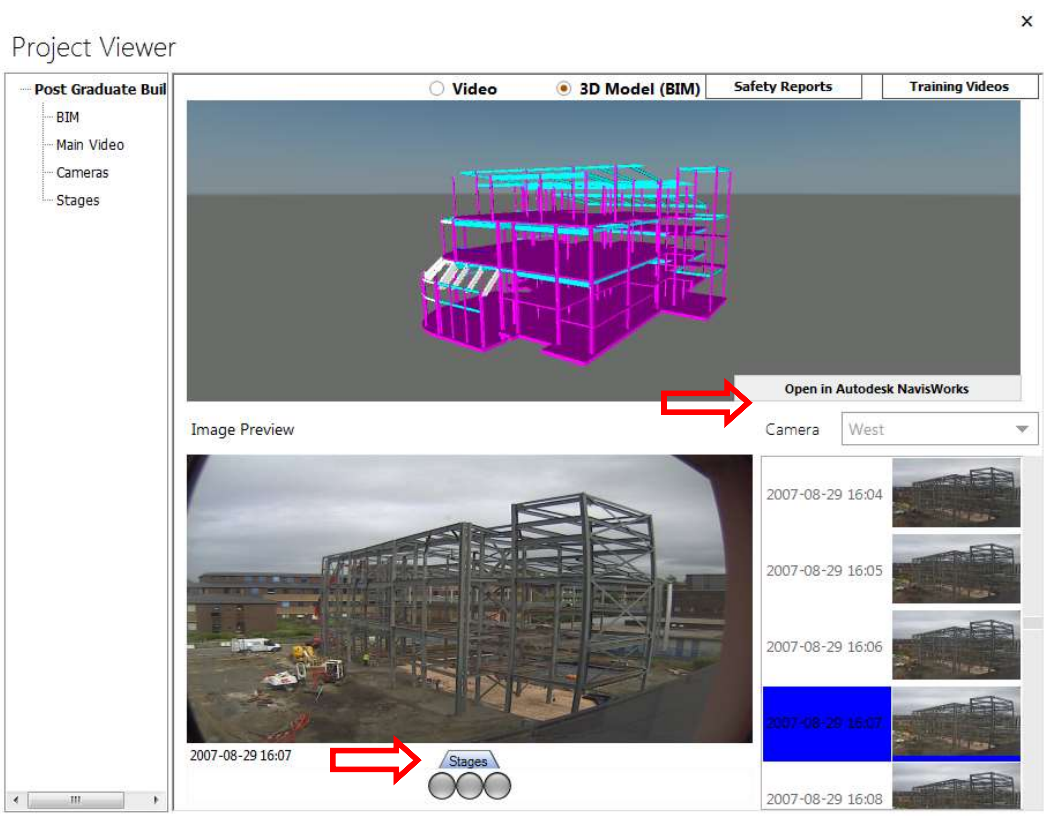



Figure (7.30): Choosing the correct stage per activity

The model developed in this research project assumes a project with three stages as an example. However, the possibility that the project can have as many stages as required was built into the existing model and the number of stages can be set by the system administrator as seen in figure (7.31).


Figure (7.31): Number of project stages

When a stage is being selected for any unclassified photo, a confirmation dialog will pop up to confirm the action, selecting "**No**", will return to the previous view, while "**Yes**" will add the photo to the selected stage as shown in figure (7.32).


Figure (7.32): Stage confirmation window

If Yes was selected, photo will be added to the chosen stage and confirmation dialog box will pop up as shown in figure (7.33).

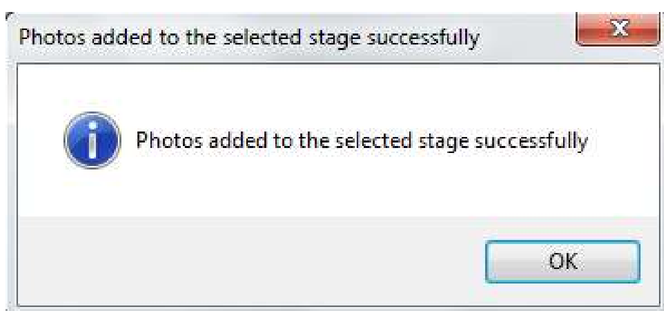



Figure (7.33): Photo addition confirmation window

In case the photo was already associated with one of the project stages, a confirmation dialog box will pop up for the user to confirm the removal of the photo from the pre-selected stage to the new one. The stage number will be shown in the dialog box for the user to get more information. Selecting "*No*" will leave the photo with the pre-selected stage while "*Yes*" will move it to the new stage as shown in figure (7.34).


Figure (7.34): Resolving conflict in photo edition

After adding any of the useful photos to one of the project stages, automatic activity recognition feature of the software can be used. In order to use that, user need to right click in any position within the image shown in the "**Image Preview**" space. A small menu will drop with only two options. The first option is "**View Stage**" which if selected will open a window with the stage details, activates within the stage, and relevant documentation as seen in figure (7.35).

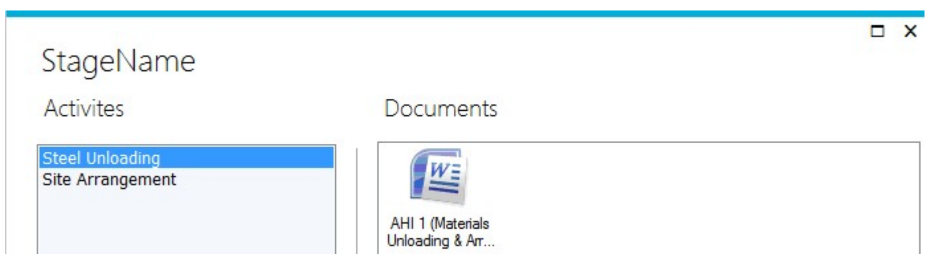



Figure (7.35): Stage name, activity, and documents related to a selected stage

The second option in the right click drop menu is "**Set Focus Rect**". Selecting that option will allow the user to use the mouse pointer to draw a rectangular shape anywhere in the photo for the software to automatically check for activity presence in the photo as shown in figure (7.36).

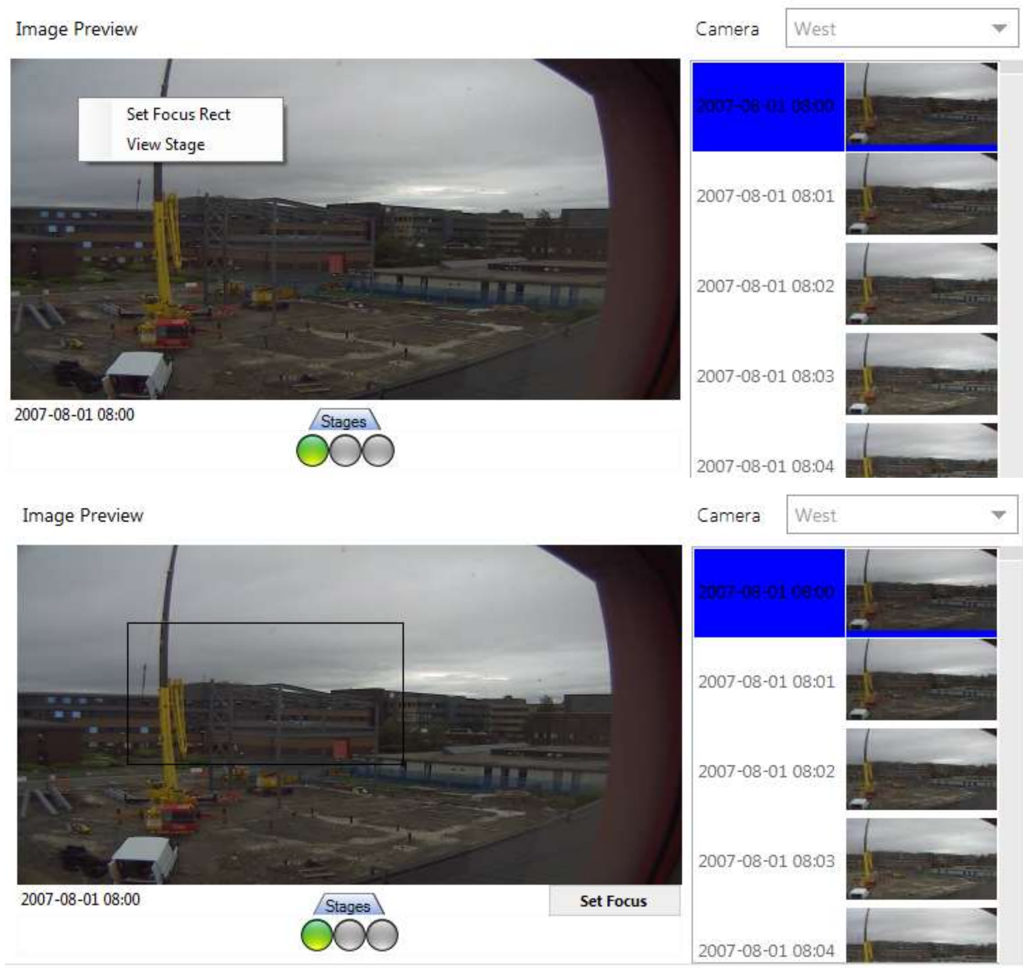



Figure (7.36): Automatic activity selection

It is worth noting that this feature incorporates the core of the software being developed for this research project. The software will undergo extended operations, by running a MATLAB code in the background which use image processing techniques to check for activity presence within a photo. If the activity is present in that specific photo the software will automatically open the relevant documentation and training files, as shown previously, while if there was no activity detected within the photo a dialog box will pop up to the user informing that there were no such activates detected as seen in figure (7.37).


Figure (7.37): Selected activity not detected in chosen screen window

As stated earlier, this operation can be performed only after adding the photo to one of the project stages. If right click is used to view the stage details or automatically detecting activates without adding the photo to a stage, an error message will pop up with the same as in figure (7.38).


Figure (7.38): Error window for not selecting a photo

All changes done to the photos stages will be saved automatically after confirmation. Closing the interface, and opening it again will not affect the stage selection of any specific photo unless manually changed by the user.

# Chapter 8- Model Verification and Validation

## 8.1 Introduction

Verification and validation are processes related to the building and quantifying of the credibility of a numerical model. These two processes collect evidence for the model's accuracy for a specific case and they are not intended to prove that the model is accurate and correct for all possible applications. The verification and validation process is considered to be completed when providing evidence that the model is sufficiently accurate (Thaker et al., 2004).

The purpose of the verification process is to ensure correct implementation of the conceptual model into its computer representation. This is achieved by ensuring that the logical structure and input parameters of the model are correctly represented. The process involves identifying and removing possible errors using various comparison methods with known numeric or experimental data. The validation on the other hand, is concerned with developing the right computer model that accurately represents the system of interest being simulated. The right model is subjective and the measure of its validity is based on how accurately its outputs correspond with those obtained from reality (Giannanasi et al., 2001).

The validation of Construction Automata includes two questionnaires and one interview, the first questionnaire aim to validate Construction Automata, the validation was achieved by conducting office and site demonstrations to a 24 professionals including 2 project managers, 2 construction managers, 2 contracts manager, 4 site safety superintendents, 4 site construction superintendents, 4 academics in civil engineering, and 6 technical engineers as shown in table (8.4). The demonstrations were followed by the participants answering a survey questionnaire whose discussion and results are detailed in the following articles of this chapter.

The second questionnaire followed by personal interview carried in order to validate Construction Automata as knowledge management tool, the questionnaire of 6 specifically related questions was distributed to the 6 members, including 2 project manager, 2 construction manager, 2 contracts managers. This was followed by a personal interview with each one of the six member to better understand their reasons behind the views expressed in their answers, as shown in Table (8.5).

## 8.2 Verification and validation

### *8.2.1 Verification*

The verification process is intended to ensure that the mathematical model representing the reality performs its intended objectives. This can be achieved by following certain modelling techniques such as: (Signorile, 2003)

1- Debugging: Commonly applied by maintaining counters within the model to ensure that all entered data had been processed.
2- Structured walk-through: Preparing documentation and explaining different aspects of the model to listeners assists the developer in being aware of possible problems or deficiencies.
3- Results testing: Checking the reasonableness of the output results for a verity of input scenarios. The model can be tested for continuity in which a slight change in input value must not result in a large change in output. Other possible tests are for degeneracy to ensure its suitability for extreme values and consistency to test that similar systems with different arrangement shall still exhibit similar characteristics.

### *8.2.2 Validation*

The validation process should demonstrate that the developed model reasonably represents the real system, Sargent (2003). Its techniques are not of a general nature but specific to the model being studied. The three specific model aspects subject to validation are: assumptions, input parameters, and output values, Hillston (2003). There are several approaches and related tests to model validations however no single test can assert that a model is validated, Martis (2006). The confidence level of any model increases gradually as it passes more and more tests, Forrester and Senge (1980). The validation strategy includes the following: (Martis, 2006)

1- Identifying and quantifying of error and uncertainty in the model.
2- Quantifying numerical errors in computations.
3- Estimating uncertainty.
4- Comparison between results and actual data.

## 8.3 Verification and Validation Philosophy and Process

The model validation process can be graphically presented figure (8.1) providing a simplified illustration of both of the modelling and simulation activity (black line) and the assessment activity (red line) as below, (Schlesinger, 1979).

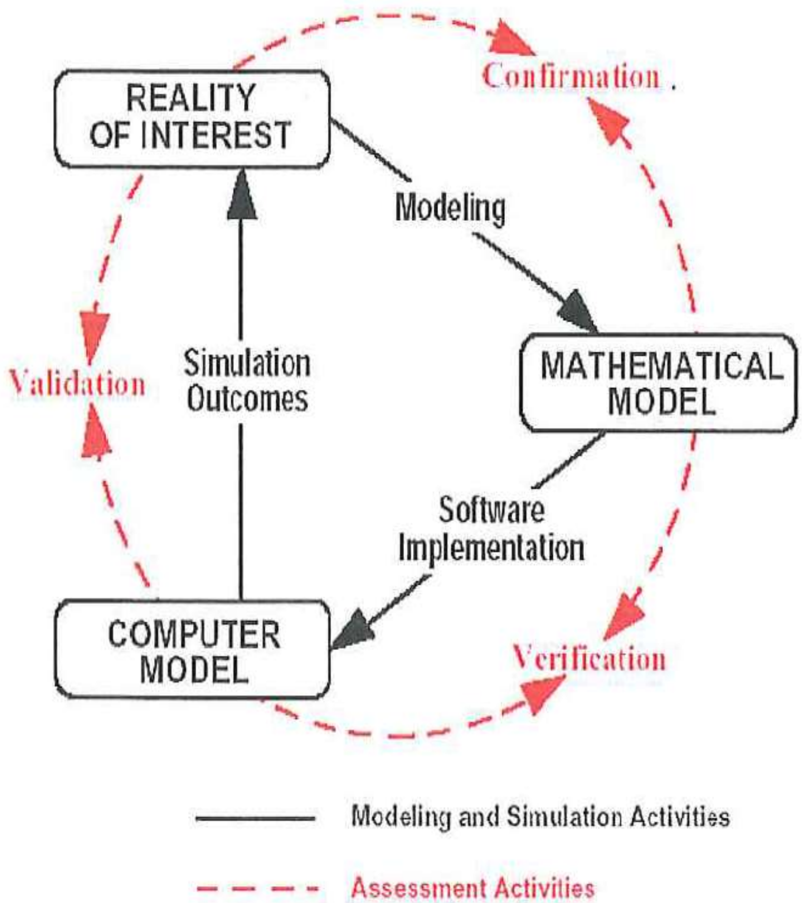



Figure (8.1): Verification and Validation Process (Schlesinger, 1979).

The Reality of interest shown in figure (8.1) refers to the problem being considered in any possible form of a unit, component, subsystem, or complete system.

The mathematical model incorporates the conceptual model, the relevant mathematical equations, and the input data that are required to identify and describe the Reality of Interest.

The Computer Model includes the mathematical modelling assumptions together with the computer program (code) and its inputs.

The Modelling activity represents the Reality of Interest in a Mathematical Model using appropriate mathematical approximations and assumptions. The confirmation activity assesses the correctness of the Modelling.

The verification activity can be divided into two components the first of which is related to the identification and removal of errors in the Code (Code Verification) and the second component is related to the Code applications (Calculation Verification).

The Validation activity quantifies the model's accuracy by comparing experimental or actual data with the Simulation Outcomes. In this sense, the Validation can be seen as an ongoing activity related to the improvement in experimental results and the range of actual data.

Figure (8.2) shows a flow chart for model development, verification, and validation (Thaker et al., 2004).

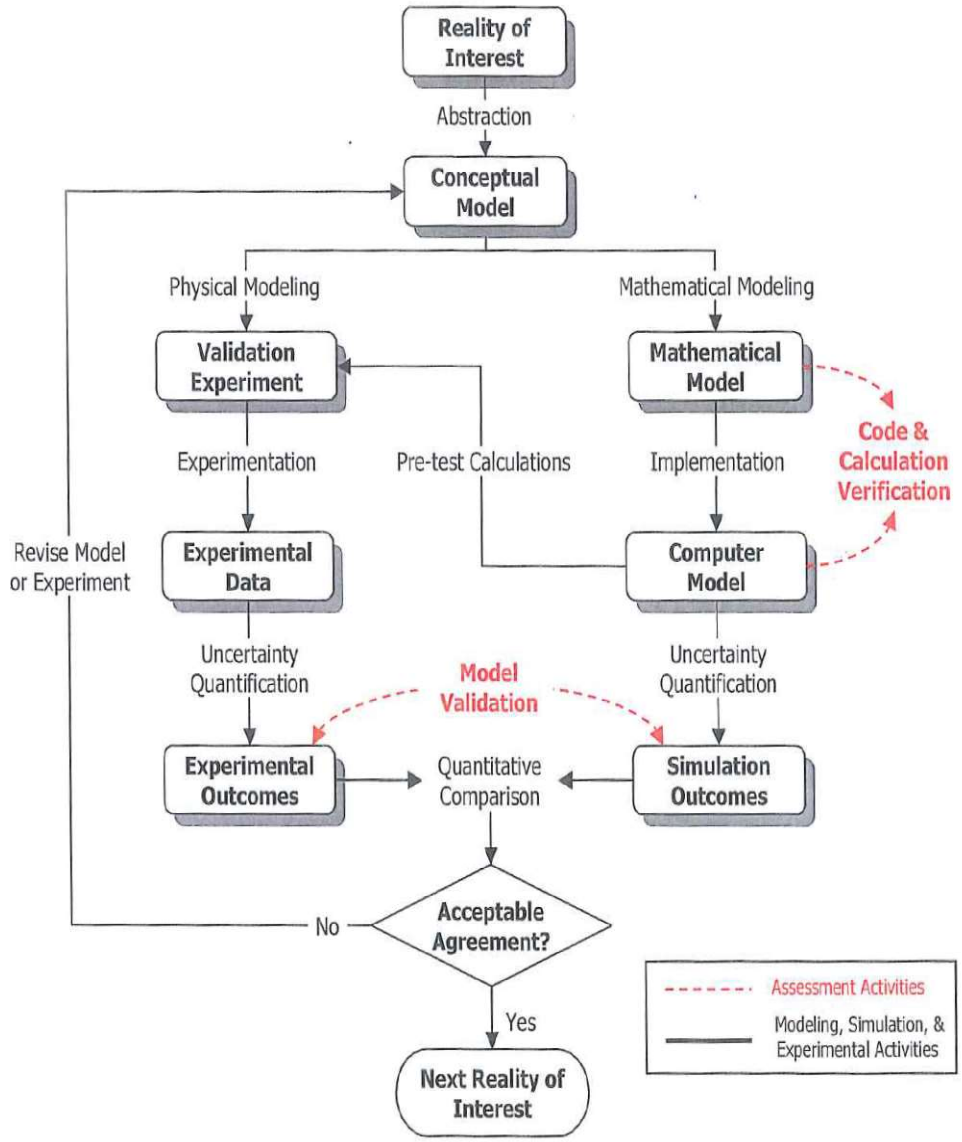



Figure (8.2): Verification and Validation Flowchart (Thaker et al., 2004).

## 8.4 Scoring model approach validation

Construction Automata, whose development was described in chapter (6), was meant initially to enhance health and safety awareness and training by providing workers with onsite training activities related to their daily scheduled work tasks. It also represents a knowledge management system enabling the automatic generation, storage, and output of site daily safety reports for accurate and timely documentation to be used as basis for the system. The fundamental tools used for these ends were the image processing of construction site digital photos and their subsequent integration with project's CAD design information. In this respect, there was a need for the resulting developed program to be evaluated by related professionals in order to confirm its practicality and usefulness.

It was realized during the development of the program that the generation of the 4D model combining the processed images and the CAD design represent an initial but significant step in compiling a BIM for the project. Although further work has to be conducted to make full use of this facility, however the preliminary results obtained by this model need evaluation in this respect as well.

The model program can be used by several professionals in various site construction activities with different levels of responsibility and hierarchy. In order for the developed program to have a wide range of application it had to be easy to operate and its results must add value in the views of its operators and end users. Construction Automata was demonstrated to twenty-four professionals in the construction, safety, and contracting activities in construction companies alongside Academics in Civil Engineering and Health and safety. Some of the demonstrations took place on site at contractor's office while others were held at the University. The site demonstrations involved the participation alongside the targeted expert of several interested personnel who reflected their insight and experience in their comments however they did not participate in answering the survey questionnaire which was limited to the targeted expert only. The model had to be explained and demonstrated to each participant which is a time-consuming exercise to both the researcher and the professional. Hence the number of participants in this process was limited however it was compensated by including as many related job positions as possible.

Construction Automata was evaluated using the scoring model approach by being presented to 24 participants, Martis (2006). The participants were presented with a questionnaire including 24 questions and were requested to give a mark from 1 to 10 for each question. This implied that the highest score for any question is (240) and the lowest is (24). The total of each question was then grouped in four ranks with (4) being the highest and (1) the lowest. The results sought from the evaluation were not just for satisfaction that the model program is practical and useful. They were also meant to highlight which part requires further work and to understand the expectations of the intended users. However, these two objectives remain as topics for future research.

The ranking marks range is shown in table (8.1) as follows:

Table (8.1): Model's Questionnaire Score Points and Rank

| **Points** | **Rank** |
|---|---|
| 24-60 | 1 |
| 61-120 | 2 |
| 121-180 | 3 |
| 181-240 | 4 |

### *8.4.1 Summary of participants*

The selection of the number of participants and their job titles have a big impact on the results of the conducted study and care should be taken in balancing the conflicting requirement implied in this exercise. The large number of participants gives more credibility to the study and produces better average ratings for its results, however finding the suitable candidates and allocating the required time on their part proved to be a challenge. Caution should also be administered when selecting the job titles and expertise of the participant. Answers from parties not directly related or not having in-depth knowledge of the subjects being addressed will skew the results and thus does not provide the required outcome. Keeping these constraints in mind a short list of recommended participants was drawn. The number of participants can be seen as rather low however it was the best that can be achieved considering the nature of the local market. The number of survey participants and their titles is shown in table (8.2):

Table (8.2): Questionnaire Experts Job Titles

| **Expert's title** | **Number of experts** |
|---|---|
| Project manager | 2 |
| Construction manager | 2 |
| Contracts manager | 2 |
| Site safety superintendent | 4 |

| | |
|---|---|
| Site construction superintendent | 4 |
| Academics | 4 |
| Engineers | 6 |
| **Total** | **24** |

The industry related experts were those of two local engineering contracting firms. The fact that the different job titles for each group comes from the same firm was seen to have a positive value as the group of professionals are working within the same system and regulations thus eliminating any conflict resulting from the firm rather than the job.

The Academics were senior university staff having the post of assistant professor as a minimum in the fields of engineering and management. The engineers were site engineers in existing local work sites responsible for project management and site safety.

### *8.4.2 Validation process flowchart*

The sought validations to the relevant modules of Construction Automata obtained from the participants is shown in red against the model's flowchart in figure (8.3).

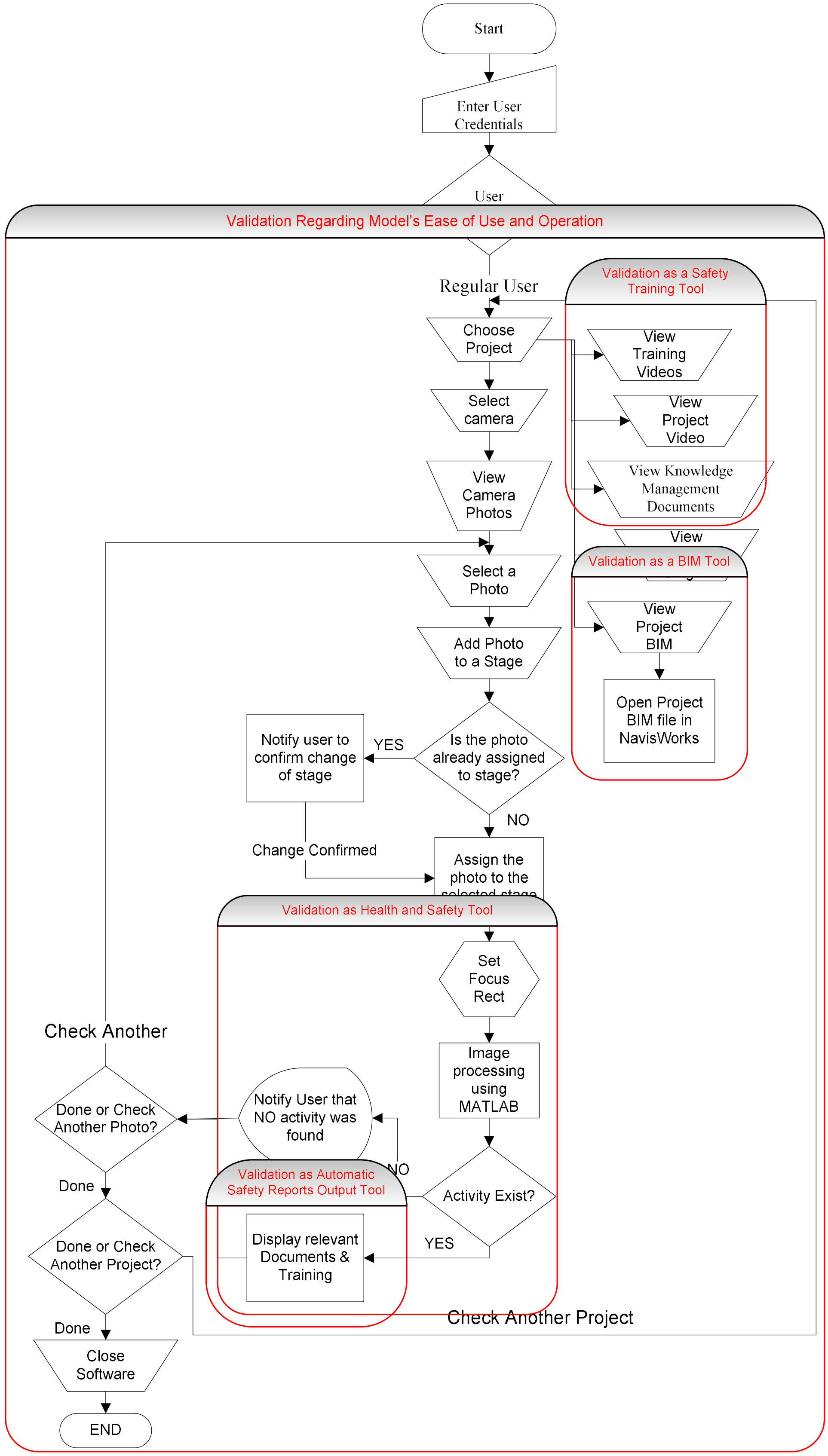



Figure (8.3): Validations related to Construction Automata modules

### *8.4.3 Construction Automata demonstrations results*

The first demonstration objective was to evaluate the response of the participant regarding operating the model. A short demonstration on the laptop on which the model was loaded was enough for senior staff acquainted with computer applications for them to operate the model.

The evaluation process after this initial step took a more specific approach by seeking feedback related to definite jobs. The overall results shown in table (8.3) were meant to reflect a general view regarding the model. This is due to the fact that some participants gave ranking marks related to jobs not within their responsibility and hence in-depth knowledge but as a general opinion based on their site experience. The model's results obtained from the case study are stated in Appendix (D) however a summary is shown in table (8.3).

Table (8.3): Summary of Questionnaire Results

| | Model effectiveness and adding value | | | | |
|---|---|---|---|---|---|
| Expert's Total Number | Model ease of use (A) | As H&S tool (B) | AS BIM tool (C) | As report output tool (D) | As video training tool (E) |
| 24 | | | | | |
| Overall Total | **150** | **154** | **120** | **127** | **114** |
| Overall Rank | **3** | **3** | **2** | **3** | **2** |

The overall results were in the middle range between grades 2 and 3 with no function receiving the highest or lowest grade. This is expected due to the stated fact that some participants gave points on subjects not directly related to their jobs.

However, to put the results in a better perspective the Experts were divided into three sub categories depending on their site and relevance to work positions. The project, construction, and contracting managers were grouped as managers. The site safety and construction superintendents were grouped as superintendents while the academics and engineers were grouped as technical. The re arrangement is reflected in table (8.4) to show the average mark per group.

Table (8.4): Questionnaire Mark per Group and Function

| Group | (A) | (B) | (C) | (D) | (E) | Average |
|---|---|---|---|---|---|---|
| Managers | 6.33 | 5.66 | 5.5 | 3.83 | 3.66 | 4.99 |
| Superintendents | 5 | 7.25 | 3.75 | 5.875 | 6.625 | 5.7 |
| Technical | 7.2 | 6.2 | 5.7 | 5.7 | 3.9 | 5.74 |
| Mean | 6.17 | 6.37 | 4.98 | 5.13 | 4.71 | |

The conclusion that can be drawn from table (8.4) is that there is still more work to be done in order to accept the developed model as a project management tool. This result is reflected in the total average mark of the managers' category and the total average mark of column (C) related to ranking the model as a BIM tool. This fact had been recognized throughout the course of this project by stating that this subject is recommended to be a topic for future research and further development of the model. However, the results do indicate that the model is suitable to what it was initially intended to be as a practical health and safety tool. This is reflected in the total average marks of columns (A) and (B). In this respect, the total average mark of the superintendents' category, being the group primarily related to this aspect of the model, is significant.

### 8.5 Validation results related to model relevance to Groups

The validation was done at different stages. The first validation required was the relevance of the developed model in principle. The intention was testing the applicability and operability of the model within the constraints of a construction site Another important feedback required was about the level of satisfaction with output reports and training material in content and quality.

1- The model ease of use and application:

The model's ease of use scores shown under function (A) in table (8.3), were supposed to reflect this feature in relation to the three groups defined in table (8.4) and are reflected in figure (8.4):

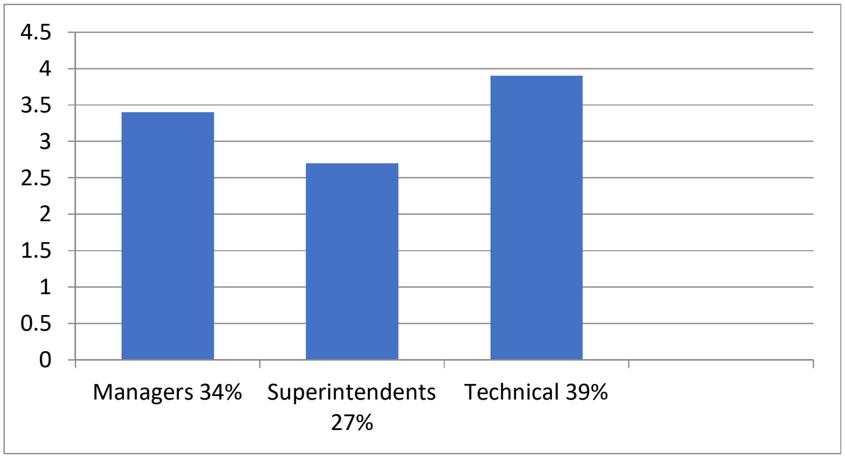



Figure (8.4): Model's ease of use per Group

Figure (8.4) shows relatively equal results for the three groups from which indicates that the model application is user friendly. This conclusion is based on the fact that the close results show that each of the groups had almost the same level of capability in operating the model and saw that the form in which its outputs are presented is sufficiently satisfactory. The fact that the highest score was from the Technical group and the lowest score was from the Superintendents group is logical given the high experience of the Technical group in the application and understanding of computer models.

2- Model's groups relevance as a H&S tool:

The developed model was intended as a health and safety tool and its relevant scoring results are shown under (B) of table (8.4). The fact the mean for this group of (6.37) shown in this table and being the highest among all other groups confirms that it was successful in performing this objective. The model relevance as a health and safety tool, function (B) in table (8.4), in relation to each group is shown in figure (8.5):

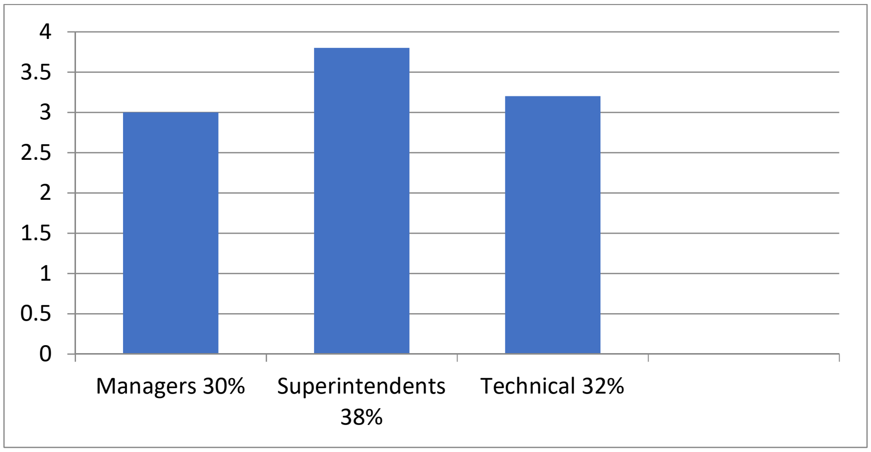



Figure (8.5): Model relevance as a H&S tool per Group

The scores shown in figure (8.5) indicate that all groups recognized the model's relevance to health and safety by scoring close percentages within 10% of the total, however the highest relevance was cited by Superintendents due to their close relation with site health and safety issues and their appreciation to what the model can achieve in its enhancement.

3- The Model's group relevance as a BIM tool:

The Building Information Model is a very effective method of project management and control (Yan and Damian, 2008). However, the developed model in this project did not consider it as its prime objective. The generated 4D model generated by integrating the 3D CAD design with the time schedule for the purpose of identifying the work stage, work activity, and associated hazards was found to be capable of creating an initial platform for the launching of a comprehensive knowledge management system such as BIM. This opportunity was recognized bearing in mind that its development to its full potential requires a dedicated initiative. The results obtained for the model relevance as a BIM tool, function (C) in table (8.3), have to be viewed within this perspective. The mean value score of (4.98) for function (C) shown in table (8.4) being under the (5) mark reflects the fact that all groups' expectations regarding the model being a BIM tool were not met. The results for the model relevance as a BIM tool in relation to all groups are shown in figure (8.6):

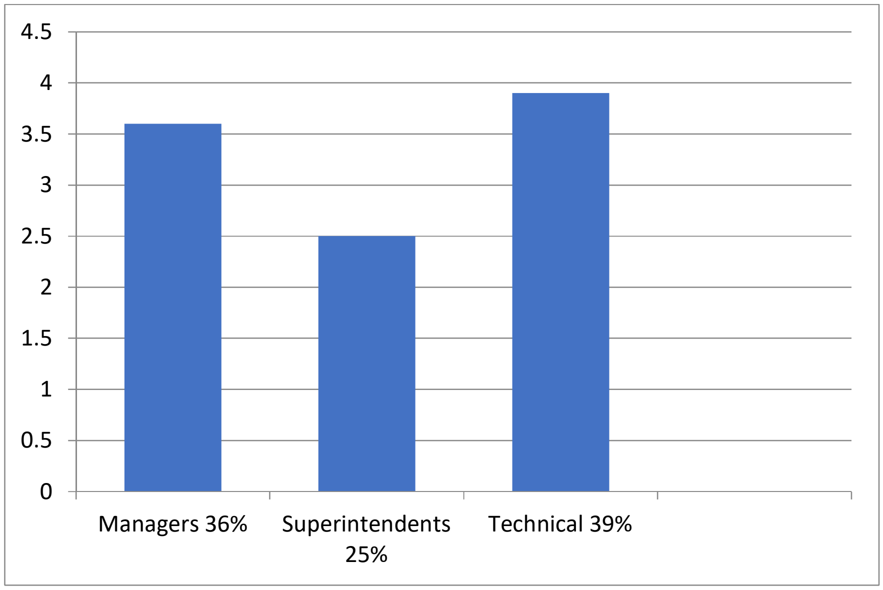



Figure (8.6): Model's relevance as a BIM tool per Group

4- Both the Managers and the Technical groups had relatively equal recognition of the model as a BIM tool. The lower percentage associated with the Superintendents group is understandable given their limited understanding of the BIM benefits due to the fact of it not being in the direct line of their responsibility. The model group relevance as a safety report automatic output tool:

The model's relevance as an automatic safety report output tool shown as function (D) in table (8.3), is one of the main objectives of this research project. It is worth mentioning that the model can easily be modified to output other project reports related to the BIM. The mean of (5.13) for function (D) shown in table (8.4) is rather low although it is above the (5) mark. This indicated that it can be considered as satisfactory however it still requires further development in content and form to meet the expectations of end users. The results of the model's relevance as a report output tool are shown in figure (8.7):

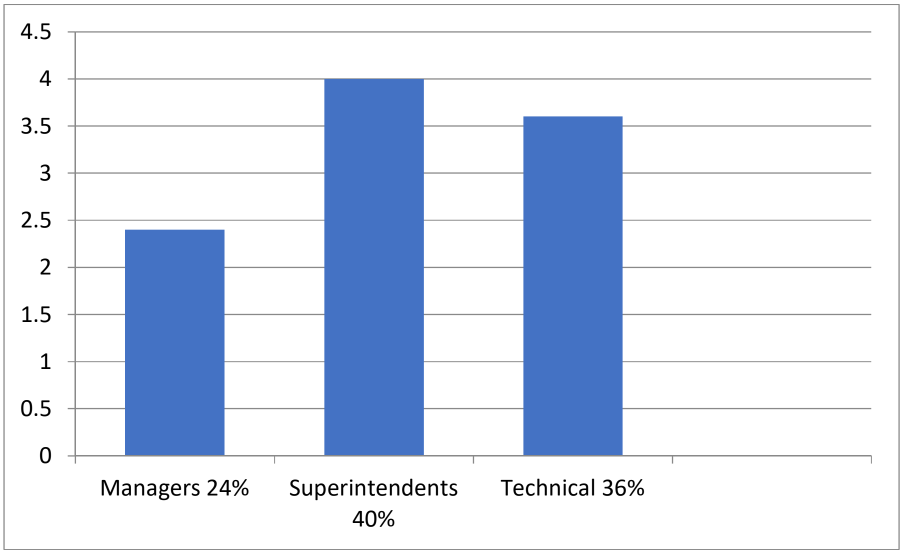



Figure (8.7): Model's relevance as a report automatic output tool per Group

It is clear from figure (8.7) the high importance which the Superintendents group had put on the automated safety report output and the editing features which the model allows. These features save time and eliminate errors which are essential in the superintendents every day job.

5- The model group relevance as a video training tool:

The model's relevance as a video training tool reflected under function (E) in Table (8.3) is another important objective of this project. This is based on the fact that visual training was found to be more effective that training briefings or lectures Arsalan and Kivrak (2014). The mean number of (4.71) indicated in table (8.4) is rather low however the discussions with the survey participants revealed that it was due to the limited choice of output videos which render them not directly related to the intended purpose of the training session. This fact gives comfort that more detailed videos reflecting different safety requirement will meet the expectations of the end users. It is worth noting here that the developed model did set the basis for this exercise which can be expanded based on und users preferences and selections. The results of the model's relevance as a video training tool are shown in figure (8.8):

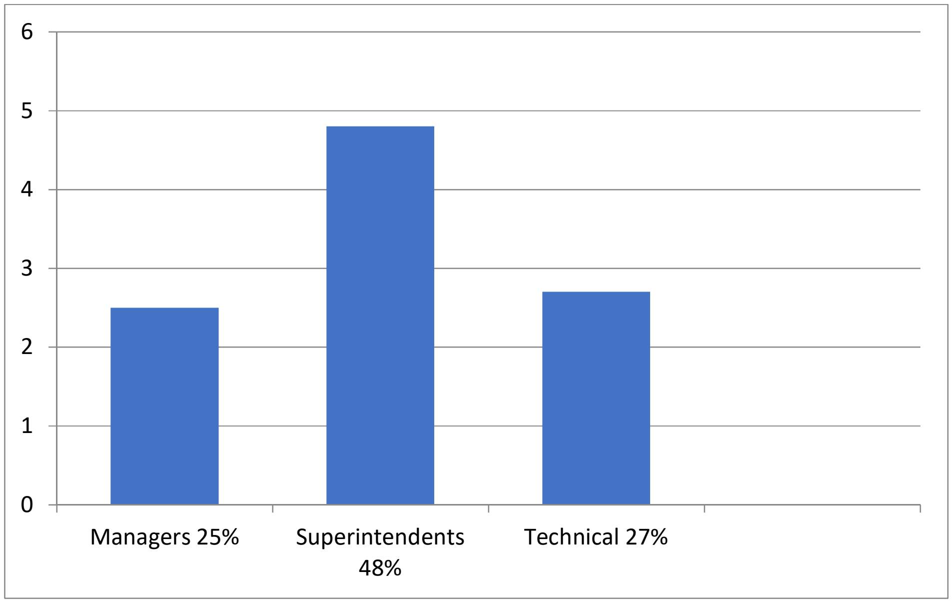



Figure (8.8): Function (E) per Group

Figure (8.8) reflects clearly the importance of training videos to Superintendents. The effectiveness of this method was recognized by them due to the fact that it captures the attention of workers and caters for the illiterate group.

## 8.6 Validation results related to model relevance to functions

The model is an abstraction of the system it is simulating. The assumptions made about the system shall result in some degree of inaccuracy however the model should implement the assumptions correctly and ensures that they are reasonable with respect to the system, Hillston (2003). Even with the stringent application of these criteria, there is no absolutely valid model. The validity of a model can be claimed against its intended use and its prescribed conditions, Martis (2006). Accordingly, the model functions (A-E) described in (Table 8.3) were analysed based on their importance to each of the three groups. Their relevance could vary from one group to another with certain groups giving a low relevance percentage. This should not be viewed as a discrepancy as its reason could be attributed to relation between the specific nature of the function and group. The validation criteria adopted was that if a function is relevant to any group then it will satisfy the condition of usefulness.

1- The model's functions relevance to the Managers group:

The model's functions relevance to the managers group presented in table (8.4) is shown in figure (8.9):

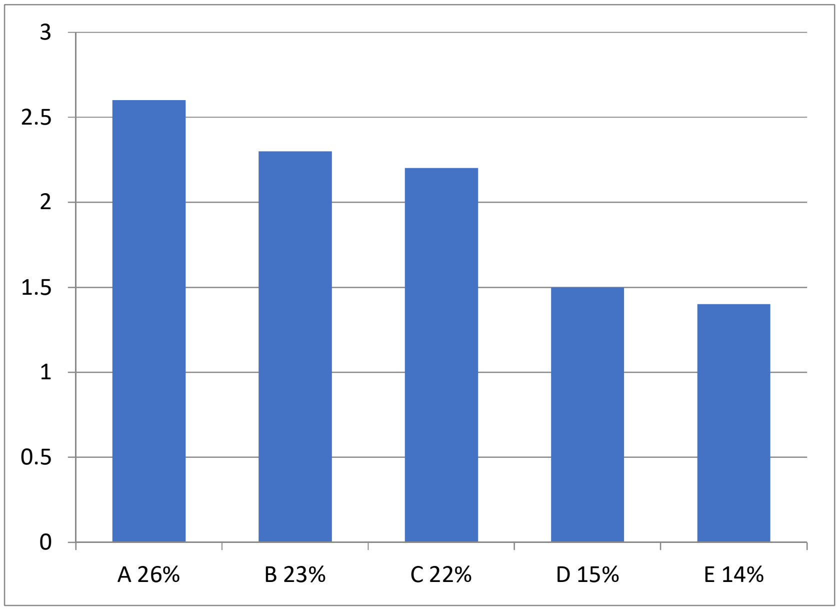



Figure (8.9): Functions Relevance to Managers Group

The results reflect the low interest of Managers in the automated reports output and the video training features. However, they gave almost equal weights to the Health and Safety and the BIM applications being the more applicable features in their discipline. The results can be seen to reflect the managers' opinion of the potential of the developed model represented in its flexibility to cater for more specific objectives.

2- The model's functions relevance to the Superintendents group:

The model's functions relevance to the Superintendents group is shown in figure (8.10):

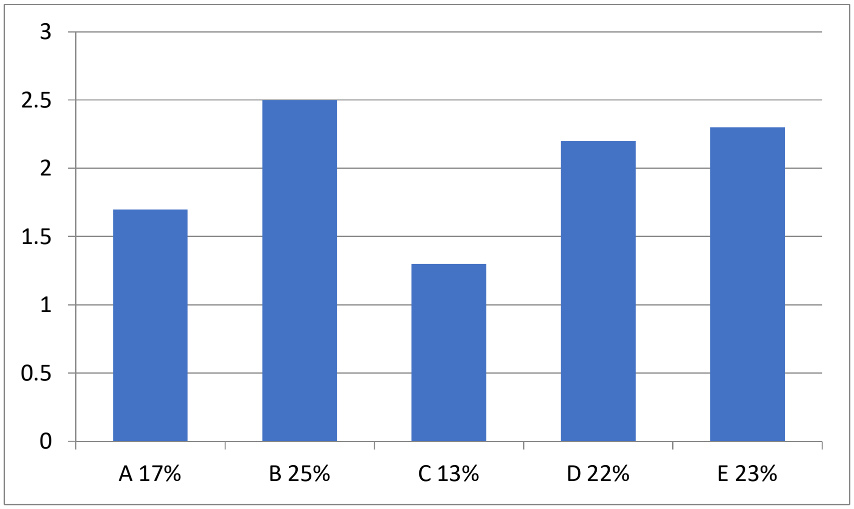



Figure (8.10): Functions relevance to Superintendents Group

It is clear that this group is concerned with the Health and safety, automated reports output, and video training which are in line with the work duties associated with this group. Their lack of interest in the BIM application is due to it being not within their line of duties which is reflected in the low percentage of the (C) function. The relative difficulty in operating the computer model of this group is also reflected in the low (A) percentage related to the ease of use function.

3- The model's functions relevance to the Technical group:

The model's functions relevance to the Technical group is shown in figure (8.11):

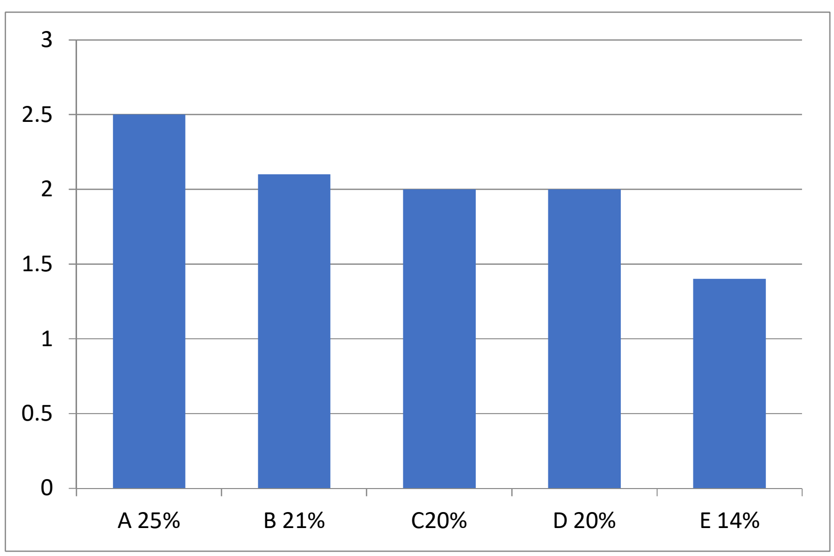



Figure (8.11): Functions Relevance to Technical Group

The results for this group show equal importance associated with all activities other than the training video activity reflected in function (E). Again, this indicates the effect of the Group’s nature of work on the various functions of the model.

### 8.7 Construction Automata knowledge management potential

The techniques and tools used in knowledge management have been in place for some time and are continuously evolving. The first-generation tools were used to spread knowledge and ideas like emails, intranet, and portals. The second generation advanced from knowledge spreading to knowledge creation with systems like wiki, forum, and blogs (Kanapeckiene et al., 2010).

The intranet and extranet technologies have been a transforming factor in spreading information and knowledge. Search and retrieval engines with improved algorithms ensured simpler retrieval and result in a free and relevant pattern matching results. Groupware can join the forces among team members facilitating group negotiation, and efficient team work. (Kanapeckiene et al., 2010).

Search engines probe within the available large amount of data within the internal or external storage such as World Wide Web giving keyword dependent data which can be random or unrelated. In this respect, the Intelligent Agent role becomes important as it has the capability to learn how the users work, what type of information they want, and what are their preferences. Information mining is another method which collects data using artificial intelligence. It is used in the extranets of a project to analyse the downloading and uploading of documents. The construction industry is characterized by its large use and exchange of documents. Electronic Document Management Systems serve to track revisions and identify the parties involved in issuing any document thus providing an efficient control platform in this industry. (Kanapeckiene et al., 2010)

The challenge in sharing information lies in accessing the right one at the right time. One of the targets of this research work is to focus on available tools and technologies enabling easy and automatic access and retrieval of the right information in the right time. In this respect, the potential of using Construction Automata as a safety knowledge management platform was investigated. This potential emerges from the fact that all the components of a safety knowledge management system are available, which are the 3D project design with time schedule, the image processing capability, and the automatic generation and output of safety report and training media. In order to pursue this subject a further questionnaire of six specifically related questions was distributed to the six members of the managers group participating in the survey (Appendix 6). This was followed by a personal interview with each member to better understand their reasons behind the views expressed in their answers shown in Table (8.5).

Table (8.5): Knowledge management questionnaire results.

| Question | Yes | No |
| --- | --- | --- |
| Do you have Knowledge management documentation system in your construction project? | 5 | 1 |
| Do you agree that knowledge management documentation system will help in spreading the knowledge through the team? | 6 | 0 |
| Do you agree that knowledge management documentation system will help to prevent similar mistake from happening again? | 4 | 2 |
| Do you think that Integrating the knowledge management documentation system with BIM under one software platform will provide efficient control in construction industry? | 6 | 0 |
| Do you think that the above integration will help in accident investigation? | 6 | 0 |
| Do you think that “Construction Automata” can provide access to the right information at the right time? | 6 | 0 |

The interview helped to clarify the results obtained for the third question. The managers expressed the view that different managers tend to act in different ways based on their previous experience. A recorded accident and the way it was dealt with which is archived in the knowledge management system can only serve as a guide and hence cannot be translated into a mandatory policy. In this respect, it cannot be said that the previous recommended preventive measures have to be adopted and hence similar accidents will be prevented. The participants also showed concern to the system's access authorization. As the system has only two modes of operators, some interviewed managers wanted further classification in order to secure the project's information and safeguard against unauthorized access.

## 8.8 Model strengths and weaknesses

The conclusions drawn from the various group's responses indicate the following points as the model's strengths and weaknesses:

Model's strength

- Easy to use
- Specifically built computer program using the latest suitable software which can be expanded to allows including variations, developments, and improvements
- Incorporates BIM and hence useful for project's scheduling, planning, and cost control.
- Automatic output of safety reports thus eliminating errors associated with the manual production.
- Provides a visual training tool suitable for daily site hazards awareness and hazards mitigating measures.
- Provides a safety knowledge management system.

Model's weakness

- Built to suit steel structure construction.
- Manual construction stage selection.
- The initial built in BIM application is limited due to the lack of associated information available for the system under consideration.
- The training videos are limited to six common hazards.
- Potential applications and future improvements
- Develop the image processing software to cater for construction activities other than steel erection.

- Test the BIM system by inputting material, scheduling, cost, and other project management related activities.
- Expand the automatic report output facility to include reports related to the BIM system together with the present Health and safety reports.
- Expand the visual video part to be able to select various training videos related to the specific activity in the selected view.

### 8.9 Summary

In this chapter, the results of the verification and validation of the specifically developed computer program were presented and discussed. The computer program was demonstrated and tested with specific photographs input and it proved to deliver its outputs according to its design. The scoring model approach was used by presenting the program to twenty-four experts in related fields. The experts were grouped in three groups of managers, superintendents, and technical. These three groups were selected on the basis that they will be able to provide an insight from different and relevant points of view regarding the practicality and usefulness of the developed model rendering their feedback suitable for validation purposes. A further questionnaire was distributed to the managers group followed by a personal interview in order to explore the potential of the developed model as a safety knowledge management tool.

The valued topics included a general point regarding the model's operation and points directly related to the objectives of the research project including health and safety, safety reports output, and video training. The utilization of the developed model as a BIM tool was also evaluated although it was realized that further and more directly related work has to be done in this area in order to recognize the model as an efficient application.

With a passing threshold of (5) marks, it was seen that the model effectiveness scored well as a health and safety and as a safety report output tool. The results also indicate that the model as a BIM and video training tool require further work and development to be recognized as an effective application in these respects. The Groups' scores were also above the passing threshold mark except for the Managers' group which can also be considered so with a mark of (4.99).

# Chapter 9- Conclusions and recommendations

## 9.1 Introduction

The historical developments in the construction industry have resulted in a need for stringent control of work progress and costs. As the manual tools in hand became increasingly insufficient or inadequate the industry resorted to automation. This need was recognized through the development of various design tools in specialized dedicated computer software packages addressing the specific requirements of the construction industry. The computerization of construction site activities follow up and control requires incorporating available site visual tools like still picture or video cameras into a system of image processing and recognition in order to be able to input the obtained visual information into specific software packages.

Another major issue in the construction industry is the site's health and safety. The construction industry and the steel erection activity in particular are considered to be prime sources of hazards and injuries. Low skill labour was also cited as a problem in countries importing this labour category. Some of this labour are either illiterate or do not speak the language of the available safety literature. The need for visual training became more important to overcome such difficulties.

Still pictures and video cameras were used in construction sites for some time however their use was limited to security recording, and providing remote site access. Their low cost and non-intrusive nature were among the advantages promoting their use. In order to have a meaningful use of their data, several computerized vision algorithms were developed and are still being developed or upgraded. The challenge is to be able to identify the most suitable algorithm for any particular application.

Computer integrated solutions which relate progress data obtained from site camera images to construction management tools are also being developed. One of the solutions gaining the industry's confidence as a comprehensive technique is the BIM analysis. In this model the CAD objects are linked to scheduling and other management tools enabling their monitoring by the image recognition techniques used.

## 9.2 Summary of research

This research addresses the development of a software package integrating the 3d CAD digital design with the time schedule information of a building at the Edinburgh compass of Herriot Watt University in order to generate a 4D model based on the input data in the form of digital images obtained from the construction process of this building. The purpose of generating the 4D model is to extract information from the images related to the stage of construction, the steel construction activities related to that stage, and the hazards associated with the activities and their mitigation. The output is the automatic generation of relevant site safety reports and a choice of video training material. The objectives of the research stated below were achieved by the envisaged strategy and the developed software package prototype and structure. A summary of actions related to each objective is also shown:

1. Identify activities of a high-risk profile within the construction industry i.e. steel construction and review previous research and literature addressing the safety issues in order to introduce automation to this field. The literature review conducted at the first stage of the research and presented in chapter (2) of this thesis pointed to steel construction as being an activity associated with a high safety hazard record. This lead to an extensive look into the hazards associated with the construction industry as a whole and that of steel construction in particular outlined in chapter (3) of this thesis.
2. Determine the extent at which computer vision techniques are used in construction sites in relation to safety issues and whether they are adequate for progress monitoring.

   Practical feedback from parties involved in steel construction was required to make this evaluation. For this purpose, a questionnaire was mailed to several construction firms and individuals and its results were shown and discussed in chapter (5) of this thesis. The received feedback confirmed the existence and output review of site visualization tools however relating their output to site's safety enhancement was not conclusive. This was a clear indication to the importance of this research.
3. Develop a computer software package capable of recognition and analysis of digital images.

The developed software package (Construction Automata) was an original piece of coding which did not rely on any available commercial package. Suitable software languages were used for each module with an extensive effort to ensure their compatibility. Chapter (6) included a detailed description of the development of Construction Automata and chapter (7) show a step by step approach to its operation. The validation of Construction Automata was achieved by conducting the case study presented in chapter (8).

4. Develop a system for identification of specific activities within steel construction and defining the safety hazards associated with these activities.
   Using the mouse pointer to draw a rectangular shape anywhere on the displayed photo for the software to automatically check for activity presence in the photo was an important and original piece of developed software. Its operation was presented in article 7.8.2 and shown in figure (7.34).

5. Automatic output of site safety reports and safety training material related to the identified activities. All the project's related safety reports and training videos can be previewed, played, or outputted by selecting any one of them from the "Project Viewer" on the main screen. This processed is described in Article 7.8.2 "Regular User Mode".

6. Knowledge Management tool to support decision making and accident investigation. The developed platform include knowledge management documentation tool, this feature allows the user to report any safety related information like safety violation or accidents, and to support the process of knowledge management such as monitoring, sharing and locating knowledge. The "Admin User Mode" described in Article 7.8.1 allows for the addition of any number of projects together with their relevant data. The "Regular User Mode" described in Article 7.8.2 can output the safety information and reports related to any of the projects included in the system. Comparing these reports facilitates the sharing of safety experience by making use of the experience and knowledge obtained from each project. The reports can also be shared with remote users thus expanding the benefits of access to past safety experiences.

This research project targeted health and safety using the output information obtained from the computer visual analysis and the project management data. The advantage of this approach is that it can provide safety instructions regarding the programmed daily construction activities thus limiting the conveyed information to the related labour force to the automatic generation of the daily safety reports which are tailored to the daily activities. Another useful output is the visual training videos which can visually display the required training information which proved to be a more effective method of passing information. The importance of site safety training was established from the survey outlined in chapter (5) of this thesis.

Construction Automata was an original piece of coding, integrating image processing using MATLAB, BIM using Navisworks, and KM documentation tool to generate health and safety documents and training material that can be viewed using advanced visualization tool. Suitable software languages were used for each part with an extensive effort to ensure their compatibility

## 9.3 Conclusions

The following conclusions were arrived at from this research project:

1- The enhancement of site construction safety in general and that of steel structure construction in particular is highly required.
2- Labor adequate training plays a significant role in reducing safety site related accidents.
3- Visual training bridges the possible cultural and language hurdles.
4- Site visualization tools are available and their output is being reviewed in construction sites however relating them to safety issues require further awareness.
5- Image analysis and processing is an effective project management technique and their application software is available.
6- Further work needs to be conducted to adapt work management software packages to cater for site safety issues.
7- Automatic safety report generation output is desired by the construction industry.
8- Project safety knowledge management system helps to prevent the reoccurrence of site accidents and facilitates accidents investigations.

## 9.4 Limitations

The validation results indicated an acceptable level of the various objectives targeted during the development of the model. However, the discussions conducted during this validation process highlighted some limitations also.

The first limitation is related to the targeted construction activity. Although steel structure erection is an important and major activity, there are many other site construction activities that are just as important. A full and a complete computerized safety and project management package based on visual image processing and analysis needs to include most if not all construction site activities. This is not an easy task and requires further extensive work both in the field of image recognition and its integration with the CAD system.

A second limitation is the level of awareness among the personnel responsible for site safety. The survey presented in chapter (5) indicated a relatively low level of daily site labour training and of the use of visualization tools in the training exercise. This low level of awareness may result in reluctance to apply new computerized site safety packages.

Another observed limitation relates to the integration of safety issues within the BIM. The present BIM packages include project management activities files and safety issues files are either not adequately addressed or not addressed at all. BIM packages include a very large data base of information from which only some safety related ones need to be selected for comparison with the CAD design information for a particular activity at a particular instant of time in order to be monitored for safety purposes. This selection's method and criteria is another challenge requiring addressing in order to develop a system including project management and safety features at the same time.

## 9.5 Recommendation for Further Research

Further research can be attempted in two areas relating to the structure and the software of the developed model. The structure part can include:

- Incorporating various construction activities other than steel structure erection.

- Automatic selection of specific BIM activities for visual monitoring. This research project included the time scheduling activity of the steel construction project to be analyzed. Other BIM activities such as cost control, material specifications, and inventories …etc. can be included in the safety developed software package and selected to view associated hazards and their mitigation.
- Expansion of the reporting and training outputs to include activities other than health and safety. The work stage and activity are being identified by the existing software model hence a relevant software can be added to automatically output their related daily reports. This can be attempted in conjunction with expanding the model to include construction activities other than steel structure construction.

The future development of the software part of the model is tied to the development or introduction of new programming packages or languages. The present cumbersome input, output, or analysing procedures might be simplified to the extent that it becomes practical to address more complicated problems. With this possibility in mind, future improvements can include:

- Automatic input of real digital data.
- Automatic activity recognition.
- Automatic selection of the relevant input data related to any particular construction activity.

And ultimately

Automatic selection of the relevant3D CAD digital input information corresponding to the various BIM activities.

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