AI-driven safety checks for ladders used on construction sites

S Hire[1], A Ranjan[1], K Ruikar[2] and S Sandbhor[1]

[1]Civil Engineering Department, Symbiosis Institute of Technology (SIT), Symbiosis International (Deemed University)(SIU), Lavale, Pune, Maharashtra, India
[2]School of Architecture, Building and Civil Engineering, Loughborough University, UK.
Email: shalaka.hire@sitpune.edu.in

Abstract. Construction plays an integral part in the social and economic development of countries worldwide. Construction site safety is a crucial concern in both developed and developing countries. Because the preponderance of safety practices is mitigation-oriented rather than prevention-oriented, the construction industry has poor safety and health conditions. Falls are the primary cause of accidents involving roof and ladder falls on site. With the ability of Artificial Intelligence (AI) based techniques, the safety of ladders can be effectively managed, and the rate of accidents can be reduced. This study presents the AI-driven safety checking for a ladder in the pre-use stage. The checks are performed in Python programming language and various libraries such as math, Numpy, and Opencv. The AI-driven safety checking can decide for 'fitness for the use of the ladder in terms of its structural rigidity before use. Compared to conventional safety practice, this process is less time-consuming, an inspection can be done throughout the project lifecycle, data can be stored and shared virtually, and needless to say, the ladder-related hazards can be reduced.

Keywords: Artificial Intelligence (AI), Construction, Ladder safety, Python, Site safety

1. Introduction

The construction sector has had a reputation for being resistant to change and hesitant to adopt new technologies, whereas, most other industries have undergone tremendous changes over the last few decades, and have reaped the benefits of the process and product innovations [1]. But that is fast changing. The need to use digital techniques increases with the scale and complexity of construction projects. Mega and complex projects involve numerous activities along with a large labour force. For the smoothly functioning of all activities and effective management of massive data, there is a need to adopt of advanced techniques. Recent trends, tools, and technologies such as Industry.4.0, Internet of Things (IoT), Artificial Intelligence (AI), big data, automation, blockchain, supply chain, Building Information Modeling (BIM), and many, others have enormous potential that can overcome the loopholes of inefficient construction practices. Considering AI, one of the flourishing technology, compared to traditional ways, its use has helped improve automation and create superior competitive advantages [2]. AI is the science and engineering of creating intelligent machines, particularly clever computer programmes, according to AI's father, McCarthy. AI is a technique for turning a computer into a computer-controlled robot or a piece of software that thinks intelligently. The growing prominence of AI in various fields has meant that its applicability is being tested in a variety of fields. Construction is one such field. The global digital transformation drive has placed a construction on the forefront of innovation. AI has the ability to automate a variety of operations and improve the construction process' efficiency [3]. Various applications of AI are being used in construction projects are to automate design, productivity, safety, quality, and scheduling and monitor and/or predict performance, among various other applications. The synchronization of AI with other platforms such as BIM also has the significant benefits in terms of digitalization and automation in construction.

This study explains how AI can be useful for ladder safety. Standard straight ladder is considered for performing the safety checks as it is widely used on global construction sites. Different paper based standard rules of ladder are codified using Python and checking of ladder is carried out. Rules such as parallel sides, angle, distance between two sides, length of ladder, are considered for checking. This process results provides decision whether the ladder is fit for use or not.

1.1 Overview of advanced trends in construction site safety

Adoption of digital technologies can contribute to increased productivity by providing efficient and effective solutions to handle numerous construction factors such as schedule, pricing, quality, information, and documentation. Nevertheless, the adoption of latest techniques are not fully explored in the safety domain[4]. Despite the fact that construction safety is the most critical parameter affecting the overall construction productivity, it is still ignored in terms of utilizing advanced methods. Majority of the construction safety practices are still traditional involving paper-based safety management, which is time consuming and not that effective [4]. The ineffectiveness of traditional safety practices is clearly visible as the rate of construction accidents is rapidly increasing. Each year, 2.3 million women and men die as a result of work-related accidents or diseases, according to the International Labor Organization (ILO), equating to approximately 6000 deaths every day. Around 340 million workplace accidents occur each year, with 160 million people suffering from work-related illnesses.

Safety management itself is a broad area in overall construction project as it is needs consideration from stage prior to commencement of actual work. Most of the safety practices are reactive rather than proactive[5]. With the applications of latest technologies safety can be managed at preconstruction stage as well as throughout the life cycle of the project. Table 1 represents the emerging trends for digital safety management.

Table 1: Emerging trends in digital safety management

Sr.no	Techniques	Summary	Reference
1	AI	It can help predict and enhance operator fitness by assisting decision-making and recognizing cognitive tasks	[6]
2	BIM	BIM has the ability to identify the hazards prior to construction with automatic safety checks	[7] [8]
3	Radio Frequency Identification (RFID)	Cellular can be used to detect collisions. Warning systems can help avoid collisions and falls. RFID systems may be used to prevent unauthorized entry to the site	[9]
4	Virtual Reality (VR)	VR can assess site safety by realistic models of current work conditions. For better training, devices include virtual images, animation, and a 3D interactive environment	[10]
5	Global Positioning System (GPS) and Geographic Information System	The safety monitoring and control system was created for the safety manager to monitor and control workers on the job site from a far with GPS and GIS	[11]
6	Cyber-physical system	Based on cyber-physical system, risk data synchronisation and mapping between virtual and physical construction sites is proposed	[12]

Various other trends such as sensor technology [13], cloud computing [14] also provide better and advanced safety solutions. The need of automation in safety particularly is not only for providing better workflow, but also to reduce the overall accident rate.

1.2 Role of ladders in construction

Ladders are primarily intended as a means of access, rather than as a working platform. According to the HSEs (Health and Safety Executive)[15] guidelines, ladders are suitable for working at heights when a risk assessment shows that deploying fall protection equipment with a higher level of protection cannot be justified, especially when the risk is modest, the period of usage is brief, and the existing workplace features cannot be changed. Ladders are often the first tool to choose when working at an elevation. Typically on a construction site, a variety of ladders are used. The duty rating, ladder type, and height required to securely execute the job task are all factors to consider when choosing the right sort of ladder. To encourage safety practices and reduce risks of permanent injury or death, the Occupational Safety and Health Association (OSHA) the regulatory body of the US Department of Labour has some recommended safety practices. As per the OSHA, there are five ladder types a Type IAA, Type IA, Type I, Type II, Type III [16]. The types of ladder along with their duty ratings and typical use are shown in Table 2. Selection of a ladder according to its intended use and working load is highly recommended by OSHA. The type of ladder that is used, would largely depend on the task at hand, the height requirement

Table 2: Ladder Types and Duty Ratings [16]

Ladder Type	Duty rating	Load capacity (In pounds)	Typical use
Type IAA	Extra heavy duty	375	Heavy duty , such as utilities, contractors and industrial use
Type IA	Extra heavy duty	300	Heavy duty , such as utilities, contractors and industrial use
Type I	Heavy duty (Industrial)	250	Heavy duty , such as utilities, contractors and industrial use
Type II	Medium duty (Commercial)	225	Medium duty, such as painters, office and light industrial use
Type III	Light duty (Household)	200	Light duty, such as light household use

and the suitability of the selected ladder for its safe use to undertake site work at a height. Standard straight or extension ladders are typically used on construction sites (Figure 1). As per the OSHA guidelines, which are principally universal for all ladder types, there are some specific requirements that are unique to a ladder type. Apart from the selection of right type of ladder, a standard approach to use and inspect it is also essential. As the use of ladder is most frequent on site, the risk of falls increase, if not adequate use or inspection routines aren't adhered to.

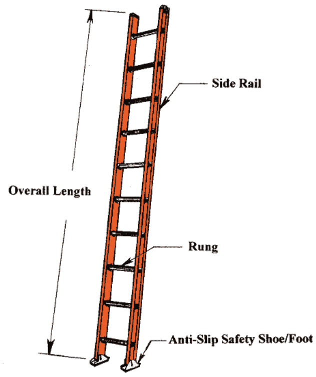

Figure 1: Straight ladder and its components. Source: (https://www.americanladderinstitute.org/page/SingleLadder)

2. Need of the study and current state of the art of hazard detection

Choosing the right ladder is for particular task is very important as wrong selection could result in increased risk of falls. Although many individuals use ladders without incident, when anything does go wrong, the consequences could be severe, resulting in serious injury or at its worse, loss of life. Ladder falls are widespread in all professions and are one of the most serious safety concerns in the building industry (IHSA). According to the Bureau of Labor Statistics (BLS), Of the 645 fatal falls in 2009, over one-third involved falls from roofs or ladders [17]. According to OSHA figures, falls account for nearly 40% of construction deaths. According to the Centres for Disease Control and Prevention (CDC), a ladder is involved in 81 percent of construction worker fall injuries treated in U.S. emergency rooms, with a substantial number of ladder accidents occurring at a height of 6 feet or less [18]. Figure 2 illustrate time-consuming the percentage of ladder fall fatalities in U.S in year 2011. Despite the significant resources and effort devoted to preventing falls, the construction sector continues to be plagued by falls and ladder incidents. Ladder slide (top or bottom), overreaching, slipping on rungs/steps, malfunctioning equipment, and poor ladder selection for a given operation are all factors that contribute to ladder falls [20]. Furthermore, using a worn or damaged ladder, throwing tools to a worker on the ladder, using metal ladders in areas where they may come into contact with electrical

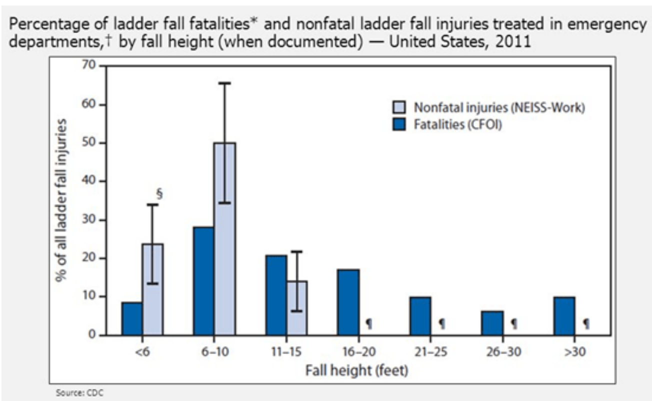

Figure 2: Percentage of ladder fall fatalities in US, 2011[18]

wires, and exceeding the ladder's weight limit all contribute to a ladder related hazard. On the whole, choosing the right ladder is essential and ensuring that the selected ladder is in sound condition is also important.

The current methods of checking ladder safety involve paper-based checklists. The identification of hazards is dependent upon paper-based plans which need to be followed strictly. This plan mainly includes inspections conducted using safety checklists, followed by maintenance. The entire process of ladder safety is time-consuming and reactions are taken after the manual identification. It is always better to have prevention than mitigation. The techniques of AI have the ability to inspect the ladder prior to use. With help of programming, the paper-based codes can be codified, and checking can be done virtually.

3. Aim and methodology

This study is a part of broader research on development of automatic safety checking model that would cater to pre-construction, construction and post-construction activities. The steps required in the automatic safety checking model for pre-construction stage include identification of hazards specially fatal four given by OSHA, which are fall, electrocution, struck by an object and caught in between [19]. Further, the 3D model preparation, rule interpretation, rule checking and reporting are the key components of automatic safety checking model. As a trial, one of the fall hazard scenarios, which is the ladder suitability is checked by methodology illustrated in Figure 3. For this study, training the AI

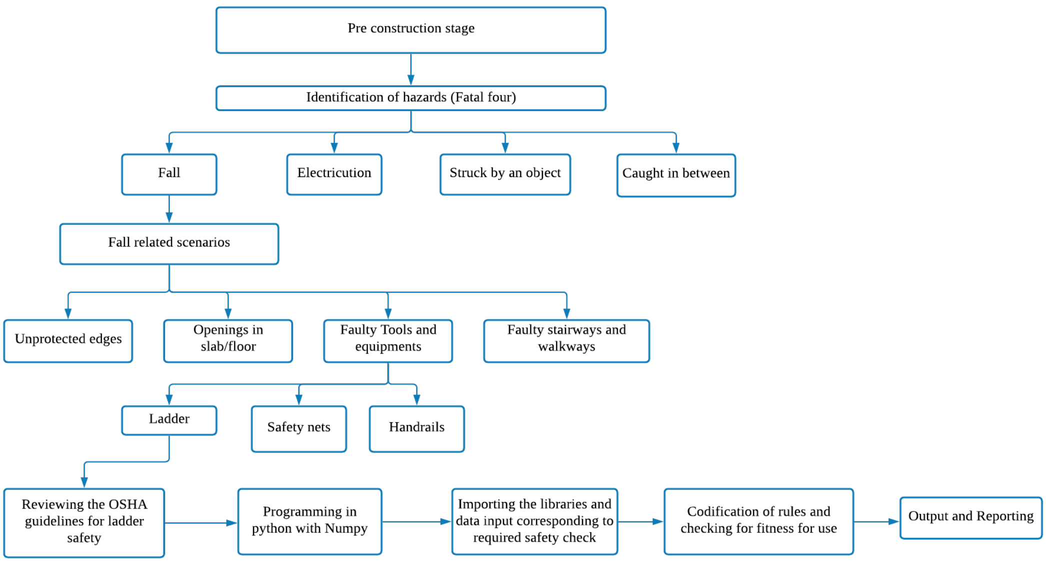

Figure 3: Flow chart of methodology for AI driven safety checking

for pre-use checking of ladder is performed. To demonstrate the typical check 'cycle' for a pre-use ladder safety check, decision tree methodology is adopted. Decision tree methodology is a commonly used data mining method for establishing classification systems based on multiple covariates or for developing prediction algorithms for a target variable[20]. It is one of the most extensively used machine learning approaches[21]. It's a supervised learning technique that can be used to solve both classification and regression problems, however it's more commonly employed to solve classification difficulties [22]. It is also used in conjunction with the Nave Bayesian Classifier to expedite precise project delay risk assessments and forecasting in Egypt's construction projects [23]. The risk of not anchoring harnesses while working on a scaffold with 40 migrant workers was assessed using neural network and decision tree techniques [26].

In this study, the decision tree helps to reach the outcome of *fit for use* or *not fit for use*. Several checks are performed for ladder safety. Firstly, the OSHA guidelines for ladder safety are reviewed. To train the AI model, the python platform is used. Furthermore, the input is given in terms of numerical data and images. With the computer vision, meaningful information from digital images gets derived and enables computers and systems to take actions or make recommendations based on that information. The edge detection approach was applied for image-based checks. The goal of edge detection is to find points in a digital image where the brightness of the image changes sharply or abruptly. The fundamental goal of image edge detection is to extract edges in a picture by finding pixels with a lot of intensity change [27]. Edges are used to determine the size of items in a photograph, to isolate certain objects from their surroundings, and to distinguish or classify objects [28]. The edge detection approach simplifies image analysis by dramatically lowering the amount of data to be processed while keeping important structural information about object boundaries [29]. The filters are utilised in the identification of the image by locating the sharp, discontinuous edges. These breaks cause variations in pixel intensities, which define the object's boundaries [30]. Several checks such as the length of the ladder, angle of inclination, parallel side rails, distance between rungs, and number of rungs are performed. In brief, the structural rigidity of ladder is checked. Check detection of failures and approval led to their use and the accumulation of successes led to selection of the ladder for its safe use.

4. AI for ladder safety

The applications of AI rely on the codification of the knowledge base that is integral to a process, some of the knowledge is explicit as a 'known' set of rules and procedures and some implicit (gained through experiential learning and heuristics) and hence 'unknown' till it is captured. The purpose of it, as with all knowledge, is to learn, continually improve and drive informed decisions. In this case, the decisions are with a purpose to drive 'safety', reduce risks and complete the planned task.

Some of the safety requirements are about the 'structural integrity' of the ladder (e.g. condition of the stiles, rungs, feet, side rails), others about the admissible loading; and still others are to drive safe practices of the human user (i.e. maintaining a three-point contact, facing the ladder at ascend and descend, wearing appropriate PPE). Other 'rules' are bounded by experiential learning and are tacitly 'known'. For example, typically, a ladder is not suitable if a task requires staying up a leaning ladder or stepladder for more than 30 minutes at a time. This collective base of explicit and tacit knowledge influences safety practices. In India, site knowledge is passed on from generation to generation through a community of site workers (e.g. Lamani communities) that live and breathe on-site. The lessons are through experiential learning practices, passed on from grandparents through sons and daughters, to their grandchildren and so on. Here, the learning is from doing and observing. However, some of these age-old practices while rich in a 'knowledge base', have witnessed losses to life or led to serious injury often due to insufficient safety consideration. The effect of 'living and breathing' on site from a young age often leads to a level of complacency when it comes 'enacting' site safety practices. While, high-end, AI-driven solutions are not an answer to this practice, they are a tool to educate the tech-savvy youth and drive a culture of safety, whilst harnessing technological capability.

To test, how AI could be used to drive a 'safety' outcome, a proof-of-concept project is being conducted. The scenario being tested is that of a straight ladder or an extension ladder. Each ladder conforms to safety standards drawn out by OSHA or HSE. Safety checks are required pre-use, in-use, and post-use. The check against these safety parameters renders its use as either, 'safe' (fit for use) or 'unsafe' (not fit for use) therefore driving the decision to either continue its use or abandon its use. Figure 4 illustrates the AI learning cycle for automated safety checks. The HSE's brief guide on safe

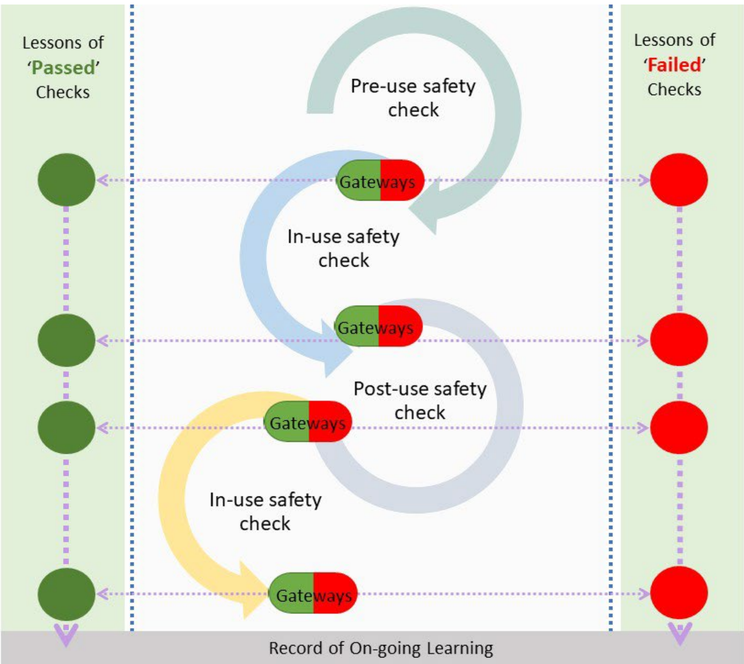

Figure 4: AI Learning Cycle for Automated Safety Checks

use of ladders and stepladders clearly states that they are not banned under the H&S law and in fact are a sensible and practical option for a low-risk, short-term use as long as the practice of its use is safe and the product (i.e. ladders) is defect free. Listed below are the typical defects to look out for at pre-use, in-use, and post-use stages.

4.1 Detecting defects in ladders

To detect defects in ladders, the HSE outlines safety guidance. These are typically instructions in plain English with a set of dos and don'ts that include graphical information (e.g. figures) to show what is correct and what is not. Some of the dos and don'ts pertain to the ladder quality requiring checks for defects, whilst others are about the ladders safe use and therefore apply to the human user. For the purposes of AI and defect checking, the focus will be mainly on defect checks, while the guidance to the human user could be via an 'alert' to remind the user (e.g. site operative) of the practices to follow in conjunction with the AI-driven approach.

4.2 Safety parameters

Various safety parameters apply at pre-use, in-use, and post-use stages. The pre-use safety parameters as outlined by the HSE, require checking the condition of stiles, rungs, feet, and side rails. Where damage has been noted, and where it threatens to affect the integrity of the ladder for its intended safe use, the decision would be to not use the ladder and notify the employer, so a more suitable alternative (that meets the safety standards) is selected in its place. A ladder that fails for each check could present risks of bucking, collapse and/or slipping among other risks. To demonstrate the typical check 'cycle' for a pre-use ladder safety check, Figure 5 is included. The sequence of checks emulates the HSE guidance. As an example, to check stiles, safety checks are needed to assess damage and to ensure that the stiles are not bent. Where any such defect is noted, the guidance requires site operatives to not use the ladder and to notify the employer due to the risk of buckling and collapse. If no such damage has been noted, the decision to proceed to the next check (e.g. rungs check>feet check>side rails) is taken. This continues as a cycle of checks at the pre-use stage. Once these checks render the outcome to be 'safe for use', the ladder is suitable for using on site. Next, a new cycle of checks begins this time with a new set of ‘in-use’ safety parameters. And, once this cycle is completed the next cycle of post-use checks commences to complete the safe use of ladder objective. As part of pre use ladders safety cycle

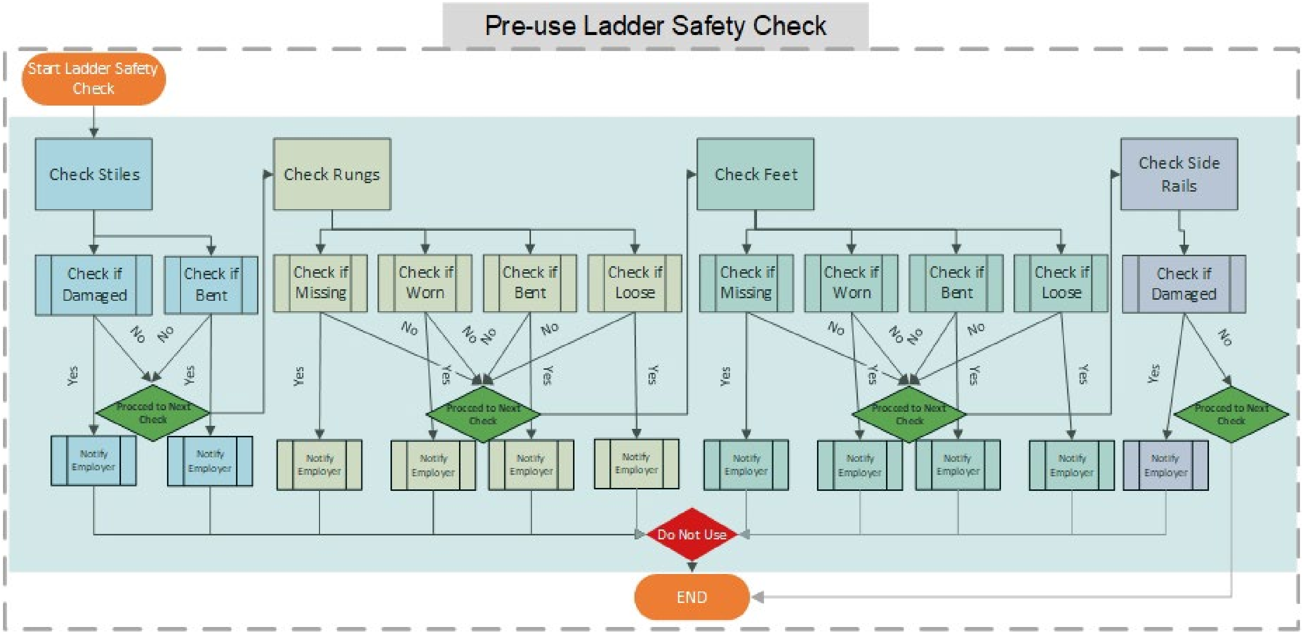

Figure 5. Pre-use Ladder Safety Check Cycle

outlined in figure above, here in this study, some of the following checks have been completed as a proof of concept. The process is divided into three main parts, i.e. Input, Process and Output. Figure 6 depicts the process adopted for AI driven safety checks in this study. The flow chart illustrates the cycle

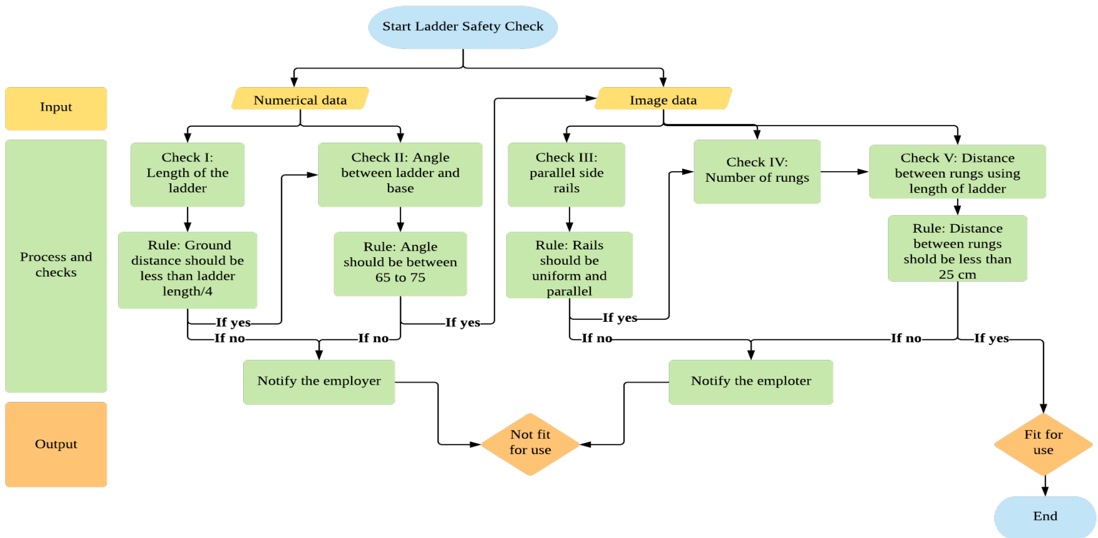

Figure 6. Sequence of pre use ladder safety checks performed in this study

for pre-use ladder safety checks. Each of the check will result in an outcome that indicates whether the ladder is fit for use or not fit for use, because of not meeting the specified condition requirements set in the OSHA standards. If it is fit, then only the next check (Figure 6) can be possible to run. Checks such as length of ladder, angle (inclination), parallel side rails, distance between rungs, and number of rungs have been performed. The checks for length of ladder and angle required numerical data as an input, whereas, for performing the checks of parallel sides, rungs the image data has been input. If the check results are *not fit for use*, then the site personnel would be notified about detected faults, record the learning, and promote optimal decisions for safe outcomes. The check process with algorithms is explained in following section.

4.3 Steps to train AI driven model for pre-use ladder safety

This section explains the checks performed in this study along with steps and algorithm for each check.

4.3.1 Check I: Adequate length of ladder and angle

At first, selection of a ladder with a standard set of dimensions is a must. To select the ladder of required length and to identify the angle between ladder and the base, the programming began with numerical data as an input. Following are the libraries imported in python to perform checking:

Listing 1: Imported libraries

```
import math
import numpy as np
import cv2
```

To find out the length and angle, math library is used. Here the two parameters such as height of wall and distance between wall and ladder base is known. The formula used for identifying the length of wall is:

$$\sqrt{Wall\ height^2 + ground\ distance^2} = \textit{Length of ladder}$$

As per the OSHA rules of section 1910.23(b)(10), any ladder with structural or other defects is immediately tagged "Dangerous: Do Not Use".[16]. Here, the term, *fit for use* or *not fit for use* is used. After identifying the ladder length, to determine whether the ladder is fit for use or not, the condition of ground distance is given as below:

Ground distance < ladder length/4 (not fit for use)

Ground distance > ladder length/4 (fit for use)

4.3.2 Check II: Angle between ground and ladder

Further, once the length of ladder resulted with fit for use, to place the ladder at suitable angle, the angle between ground and ladder was calculated using the below-given formula:

int(round(math.degrees(math.atan2(int(wall_height), int(ground_distance)))))

The stated formulae are programmed in python and checks are done. As per the standard, the angle between the ladder and ground must be between 60 to 75 degrees. If it is between these then, it is stable and safe to use.

Listing 2: Algorithm check I and check II:

```
wall_height = input("Enter the height of the wall in meters.: ")
ground_distance = input("Enter the distance between wall and ladder base.: ")
step_1 = int(wall_height)**2 + int(ground_distance)**2
ladder_length = math.sqrt(step_1)
```

```
print("The length of the ladder is ", ladder_length)
x= int(ladder_length/4)
if int(ground_distance) < int(x):
print("We need to change the ladder length")
elif int (ground_distance)>= int(x):
print("The length of ladder is good to use")
angle=str(
int(round(math.degrees(math.atan2(int(wall_height), int(ground_distance))))))
if angle > str(75):
print("The angle between ground and ladder is more than 75"+'°'+ "So, please decrease the angle")
elif angle < str(65):
print("The angle between ground and ladder is less than 65"+'°'+ "So, please increase the angle")
elif str(65) <= angle <= str(75):
print("The angle between ground and ladder " + angle + '°' + ", So no changes are require in angle")
```

After running the program successfully, the output is presented in terms of the ladder's fitness for use. Figure 7 illustrates the output of the program with result as fit for use.

```
Enter the height of the wall in meters.: >? 3
Enter the distance between wall and ladder base.: >? 1
The length of the ladder is %s 3.1622776601683795
fit for use
The angle between ground and ladder 72°
```

Figure 7: Output for check I

4.3.3 Check III: If the side rails are parallel:

As per the OSHA standard for ladders, 1910.23(b)(1) ladder rungs, steps, and cleats should be parallel, level, and uniformly spaced when the ladder is in position for use. Once the ladder is identified as fit for use with selected dimension, next check of parallel sides can be given. However, for this check the input data will be in the form of image of ladder. It should be noted that next check is possible only if the first condition of fit for use is satisfied in program. This check also detects if the distance between the sides rails is the same throughout the ladder or not. Refer Figure 8 is the image of ladder imported to perform checking.

Figure 8: Input image for safety checks

The image is imported into the program using .imread function in cv2. The imported image was further converted into a greyscale image to remove unwanted noise from the image.

Listing 3: Image import

```
img = cv2.imread("img1.jpg")
result = img.copy()
gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
```

The greyscale image is then used for Canny Edge Detection using cv2. Canny. To detect if the distance between the sides rails is the same throughout the ladder or not also to see if the side rails are parallel to each other or not we have used Hough Line Transform

- The Hough Line Transform is a transform used to detect straight lines.
- To apply the Transform, first, an edge detection pre-processing is desirable.

Here HoughLinesP() (The Probabilistic Hough Line Transform) are used. HoughLine is a more efficient implementation of the Hough Line Transform. It gives as output the extremes of the detected lines (x0,y0,x1,y1). Further, in OpenCV, it is implemented with the function HoughLinesP().

Listing 4: Algorithm for check III:

```
edges = cv2.Canny(gray, 50, 150, apertureSize=3)
cv2.imshow('edges', edges)
lines = cv2.HoughLinesP(edges, 1, np.pi / 180, 100, minLineLength=20,
maxLineGap=100)
    for line in lines:
    x1, y1, x2, y2 = line[0]
cv2.line(img, (x1, y1), (x2, y2), (0, 255, 0), 2)
# print(x1,x2,y1,y2)
def parallel(x1, y1, x2, y2):
# If slopes are equal
if ((-(x1 / y1)) == ((x2 / y2))):
print("The side rails are not parallel to each other");
else:
print("The side rails are parallel to each other");
if __name__ == '__main__':
```

```
parallel(x1, y1, x2, y2);
```

Further, the Parallel function is created under Hough Lines P to check if the rails are parallel to each other or not. If the rails are found to be parallel to each other, the codes move to the next part or else it shows the ladder is not fit for use.

4.3.4 Check IV: Number of rungs

After the successful pass checks for I and II, the next check done is for the number of rungs. To find the rungs in the ladder the length of the ladder which was found at first was used. Also, for this check, same libraries are used as used in check II. The same greyscale image is used from the above check to add the threshold value. Different codes are used for each algorithm.

Listing 5: To identify the threshold value

```
cv2.threshold(gray, 0, 255, cv2.THRESH_BINARY_INV + cv2.THRESH_OTSU)[1]
```

Listing 6: To find the threshold a horizontal kernel was added to find the horizontal rungs in the ladder:

```
cv2.getStructuringElement(cv2.MORPH_RECT, (40,1))
```

Listing 7: Further, to detect the horizontal lines

```
cv2.morphologyEx(thresh, cv2.MORPH_OPEN, horizontal_kernel, iterations=2)
```

Listing 8: To add the visual effects to the ladder and to count the number of rungs contours (highlights) on the vertical rungs are made.

```
cv2.drawContours(result, [c], -1, (36,255,12), 2)
```

Listing 9: Algorithm for check IV:

```
thresh = cv2.threshold(gray, 0, 255, cv2.THRESH_BINARY_INV + cv2.THRESH_OTSU)[1]
horizontal_kernel = cv2.getStructuringElement(cv2.MORPH_RECT, (40, 1))
detect_horizontal = cv2.morphologyEx(thresh, cv2.MORPH_OPEN, horizontal_kernel, iterations=2)
cnts = cv2.findContours(detect_horizontal, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
cnts = cnts[0] if len(cnts) == 2 else cnts[1]
for c in cnts:
cv2.drawContours(result, [c], -1, (36, 255, 12), 2)
no_rung = len(cnts)
print("The number of rungs in the ladder is ",no_rung)
```

Figure 9 represents the contours made on image for identifying the number of rungs. As per the algorithm, the number of rungs are identified and 10 rungs are detected.

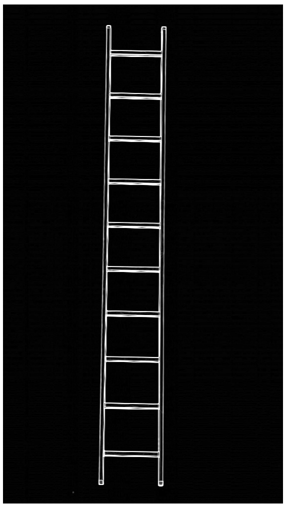

Figure 9: Contours on rungs

*4.3.5 Check V: Distance between rungs***:**
As per the OSHA standard for ladders, 1910.23(b)(2) ladder rungs, steps, and cleats are spaced not less than 10 inches (25 cm). All the rungs should be equidistant from each other.

Listing 10: Algorithm for check V:

```
final_rung = len(cnts)+1
rung_distance= str((ladder_length/final_rung)*100)
print("The distance between rungs is ", rung_distance, "CM")
```

As the distance between rings is less than 25 cm, the ladder is not fit for use. The ladder is fit for use only when all the checks performed results with fit for use.

4.4 Final check
In the final step, all the above conditions are checked to find if the ladder is fit to use or not. If the below conditions pass then the ladder will be fit for use. The check should pass the following conditions:-

- Ground distance > ladder length/4
- The angle of the ladder is between 65° & 75° it is fit for use
- ((-(x1 / y1)) not equal to ((x2 / y2)))
- The rung distance should be less than 25cm

Listing 11: Algorithm for final check:

```
if int (ground_distance)>= int(x) and \
str(65) < angle < str(75) and ((-(x1 / y1)) != ((x2 / y2))) and str(rung_distance) < str(25):
print("Yes, The ladder has passes all the conditions and is fit for use.")
print("The ladder is not fit for use");
```

As, the ladder has passed all the checks except the check of distance between rungs, so it is not fit for use. To have the ladder safe for use, all the checks needs to be pass and fit. Figure 10 represents the final checks and output generated for ladder safety checks.

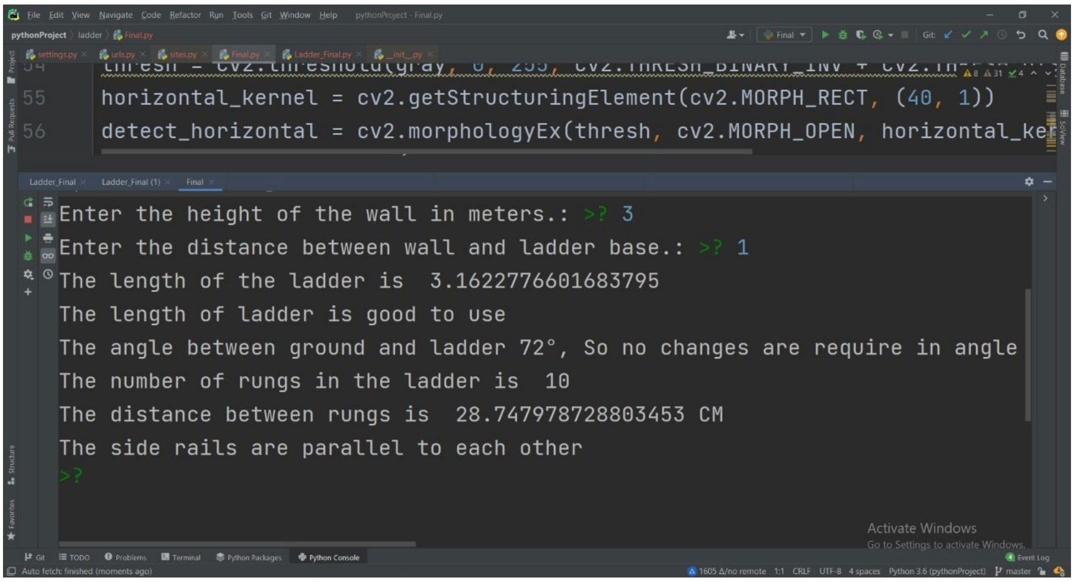

Figure 10: Model displaying final output

5. Conclusion

Ladders are the most commonly used tool in construction operations. In this age of technical innovation and data, the construction sector is transforming. The AI-driven ladder safety system proposed in this study indirectly ensures the safety of humans prior to use. The checks for structural integrity of ladder such as adequate length and angle, parallel sides, number of rungs, distance between rungs are presented in the study. The conventional approach of inspection of ladder is manual and human decisions are involved that might lead to error prone results. AI has the potential to accurately detect the faults and provide error free decisions on whether it is fit for use or not. Moreover, it also reduces the human efforts and time required for manual inspection.

Although, the output generated are accurate with the AI driven safety checks, the process of codification and interpretation of rules plays significant role in detection of faults. For that, the required input data must be reliable and accurate. The source of data required for image processing is very less and inaccurate. Besides, quality of image is primarily important as the noise at the image background causes problems. On-site work will always have background noise which requires due attention.

The automatic safety checking allows us to store the data on virtual platform preventing the loss of data and information. The study explained the process of AI driven safety at pre-use stage. Similar process can be followed for ensuring the in-use and post-use ladder safety. For future work, the programming can be integrated with drones for real time hazard detection providing better results. It can automatically alert the person in charge of ladder's safety. Also, this work is undertaken for only one type of ladder, whereas there are different types of ladders being used on construction sites. With the accurate image data, the checking can be done for several types as well.

References

[1] Benz S 1997 The project manager's CADD survival guide *Proj. Manag. CADD Surviv. Guid*

[2] Chien C F, Dauzère-Pérès S, Huh W T, Jang Y J and Morrison J R 2020 Artificial intelligence in manufacturing and logistics systems: algorithms, applications, and case studies *Int. J. Prod. Res* **58** 2730–1

[3] Kyivska K and Tsiutsiura S 2021 Implementation of artificial intelligence in the construction industry and analysis of existing technologies *Technol. Audit Prod. Reserv* **2** 58

[4] Hire S, Sandbhor S and Ruikar K 2021 Bibliometric survey for adoption of building information modeling (bim) in construction industry – a safety perspective *Arch. Comput. Methods Eng*

29 679-693
[5] Sandbhor S, Ruikar K and Hire S 2022 Paradigm Shift in Construction Processes with Industry 4.0 *Industry 4.0 in Small and Medium-Sized Enterprises (SMEs)* ed Ketan K, Satish K, Arunkumar B and Suresh R 1st edition 33-52 (Boca Raton: Taylor & Francis)
[6] Romero D, Mattsson S, Fast-Berglund Å, Wuest T, Gorecky D and Stahre J 2018 Digitalizing occupational health, safety and productivity for the operator 4.0 *IFIP Adv. Inf. Commun. Technol* **536** 473–81 (Cham)
[7] Zhang S, Teizer J, Lee J K, Eastman C M and Venugopal M 2013 Building information modeling (bim) and safety: automatic safety checking of construction models and schedules *Autom. Constr* **29** 183–95
[8] Hossain M M and Ahmed S 2019 Developing an automated safety checking system using BIM: a case study in the Bangladeshi construction industry *Int. J. Constr. Manag* **22** 1206-1224
[9] Osunsanmi T O, Aigbavboa C and Oke A 2018 Construction 4.0: The future of the construction industry in south africa *Int. J. Civ. Environ. Eng* **2** 206–12
[10] Zhou Z, Irizarry and Li Q 2013 Applying advanced technology to improve safety management in the construction industry: a literature review *Constr. Manag. Econ* **31** 606–22
[11] Zhou W, Whyte J and Sacks R 2012 Construction safety and digital design: A review *Autom. Constr* **22** 102–11
[12] Jiang W, Ding L and Zhou C 2019 Cyber physical system for safety management in smart construction site *Eng. Constr. Archit. Manag* **28** 788–808
[13] Naticchia B, Vaccarini M and Carbonari A 2012 A monitoring system for real-time interference control on large construction sites *Autom. Constr* **29** 148–60
[14] Barata J and da Cunha P R 2019 Safety is the new black: the increasing role of wearables in occupational health and safety in construction *Lect. Notes Bus. Inf. Process* 526–37 (Cham)
[15] Health and safety Executive 2012. Health and Safety Executive Essentials of Health and Safety at Work Health and Safety Executive Health and Safety Executive *Heal. Saf. Exec* 1–105
[16] Occupational Safety and Health Administration 2012 1910.23 - Ladders. | *Occupational Safety and Health Administration* **23**
[17] U S Bureau of Labor Statistics and U S Department of Labor 2012 Number of Fatal Work Injuries 1992 – 2009 Rate of Fatal Work Injuries 2006 – 2009 Fatal Work Injury Rate *Popul (English Edition)* 1992–2009
[18] Centers for Disease Control and Prevention USA 2014 Morbidity and Mortality Weekly Report *MMWR Surveill. Summ* **63** 293
[19] Union I 2011 Fall Hazard Recognition , Prevention & Control – Student's Manual A Program of the Health & Safety Department International Union, UAW
[20] OSHA 2011 *Construction Focus Four: Outreach Training Packet Module* Directorate of Training and Education
[21] Song Y Y and Lu Y 2015 Decision tree methods: applications for classification and prediction *Shanghai Arch. Psychiatry* **27** 130–5
[22] Patel H H and Prajapati P 2018 Study and analysis of decision tree based classification algorithms *Int. J. Comput. Sci. Eng* **6** 74–8
[23] Suter D and Li Q 2015 Artificial Intelligence Decision Trees at *Harbin Inst. Technol. - Dellivered Course*
[24] Gondia A, Siam A, El-Dakhakhni W and Nassar A H 2020 Machine learning algorithms for construction projects delay risk prediction *J. Constr. Eng. Manag* **146** 1–16
[25] Goh Y M and N F Binte Sa'adon 2015 Cognitive factors influencing safety behavior at height: a multimethod exploratory study *J. Constr. Eng. Manag* **141** 04015003
[26] Sha, N Mehra, R and Sharma L 2015 Comparative analysis of canny and prewitt edge detection techniques used in image processing *Int. J. Engi. Tr. and Tech* **28** 48-53
[27] Jeyalaksshmi S and Prasanna S 2016 A review of edge detection techniques for image segmentation *Int. J. Da. Min. Tech.. and App* **5** 140–142

[28] Canny J 1986 A computational approach to edge detection *IEEE Trans. Pattern Anal. Mach. Intell* **6** 679–698
[29] Shrivakshan G and Chandrasekar C 2012 A comparison of various Edge Detection Techniques used in Image Processing *Int. J. Comput. Sci* **9** 269-276