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# A Fault Tree Analysis (FTA) Focusing the Design Attributes and Decision Tree Analysis (DTA) Comparing Payload: Weight for Various Adhesive Mechanism of Wall Climbing Robot

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**Abstract** - Wall Climbing Robot(WCR) has become the need of the hour to accomplish many risky task in industries for various application. There are many research outcomes for the better design of this WCR, but still there is scope for improvement in design. In this paper, a fault tree analysis focusing the design attribute is presented for a Wall climbing robot and a comparison on its two key design element like payload(p) and weight(w) is done across various types of adhesive mechanism like bio inspired, electro adhesive, rope and rail and chemical adhesive type using the Decision Tree Analysis. With rapid growth in technology, the scope for research in this area has widen up to enhance the performance of the bot. To propose an innovative design, it is essential to understand the existing design and its value (ie p: w), such that the repetition of design can be avoided and this also helps the researcher to know how to arrive an optimal design. This paper helps a beginner to understand in how to choose an appropriate adhesive mechanism for wall climbing robot when payload and self-weight of WCR are considered as important parameter for the application

***Keywords*** *– Wall Climbing Robot (WCR), Fault tree Analysis(FTA), Decision Tree Analysis(DTA), payload(p), weight(w)*

## 1. Introduction

The wall climbing robot with high payload and less weight has high advantage in terms of enhanced performance. Especially when we talk about the industrial application this key attribute p: w has to be considered while constructing the design and fabricating the bot for practical implementation in the real time environment. Almost all the challenges could be solved or in other words a better design could be introduced when our focus is on p: w value. In this article, novelty is introduced by using two different reliability engineering tool namely fault tree analysis and decision tree analysis. The main parameter payload (p) and weight(w) is considered via fault tree analysis and a decision tree analysis is used as a tool for analyzing the p: w value of existing wall climbing robots with variable adhesive mechanism like bio inspired, electro adhesive, rope and rail and chemical adhesive. Finally, a conclusion is derived comparing these adhesive mechanisms to find out which mechanism possess higher positive integer value of p:w

## 2. Fault tree diagnose for identifying the failure in WCR

The design parameters determine the performance of the wall climbing robot. These parameters can be broadly classified based on the adhesive mechanism and locomotive type. The choice of these parameters is purely based on the application where it is to be used. In this fault tree diagnose as shown in fig [1], it is clear that for a wheel type locomotive wall climbing robot, the failure occurs because of various factors out of which less payload and more self-weight is found to be the major reason.

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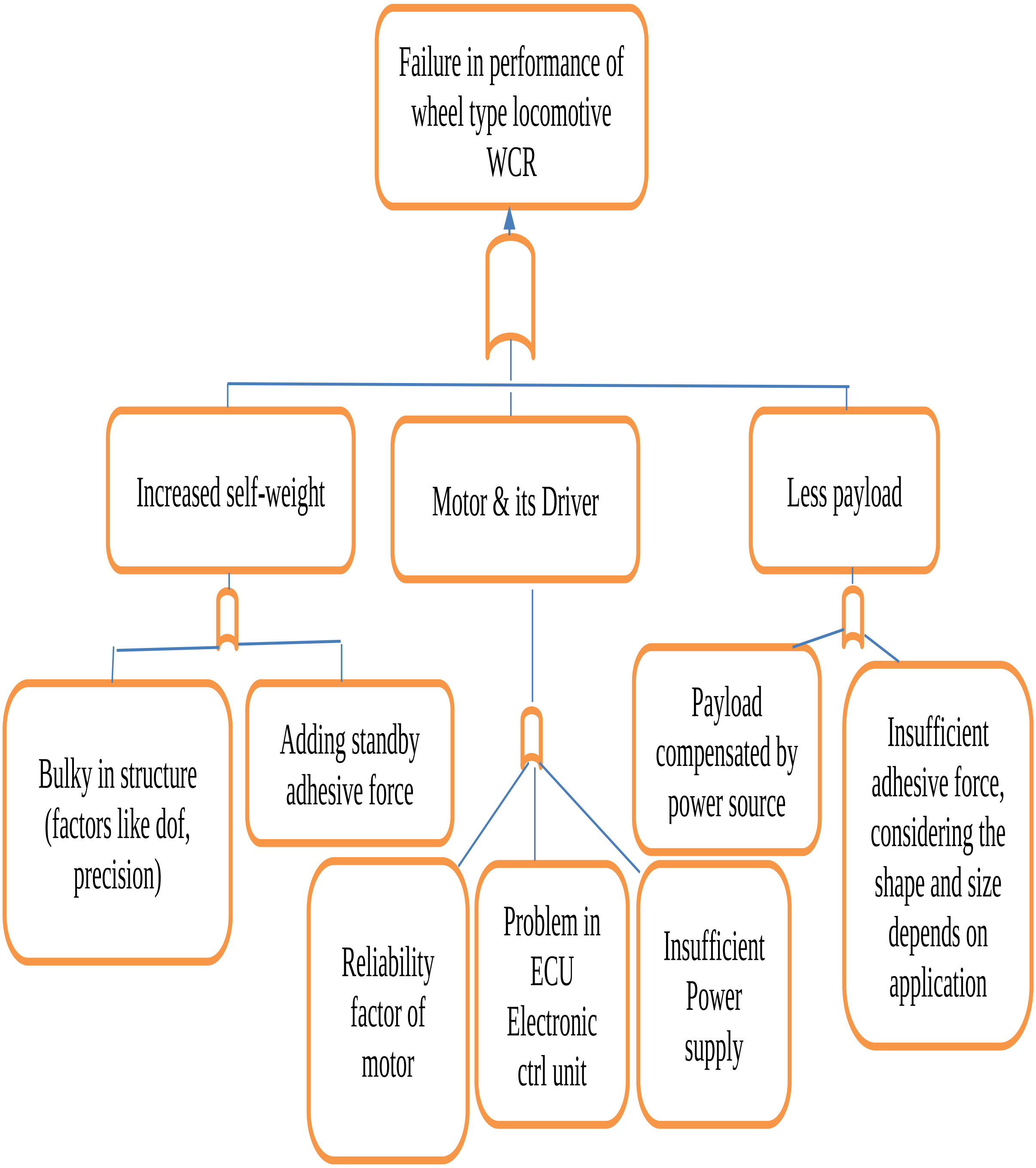
**Fig 1.** Fault Tree Analysis for identifying the failure in WCR



**1. Bio inspired Adhesive Type**

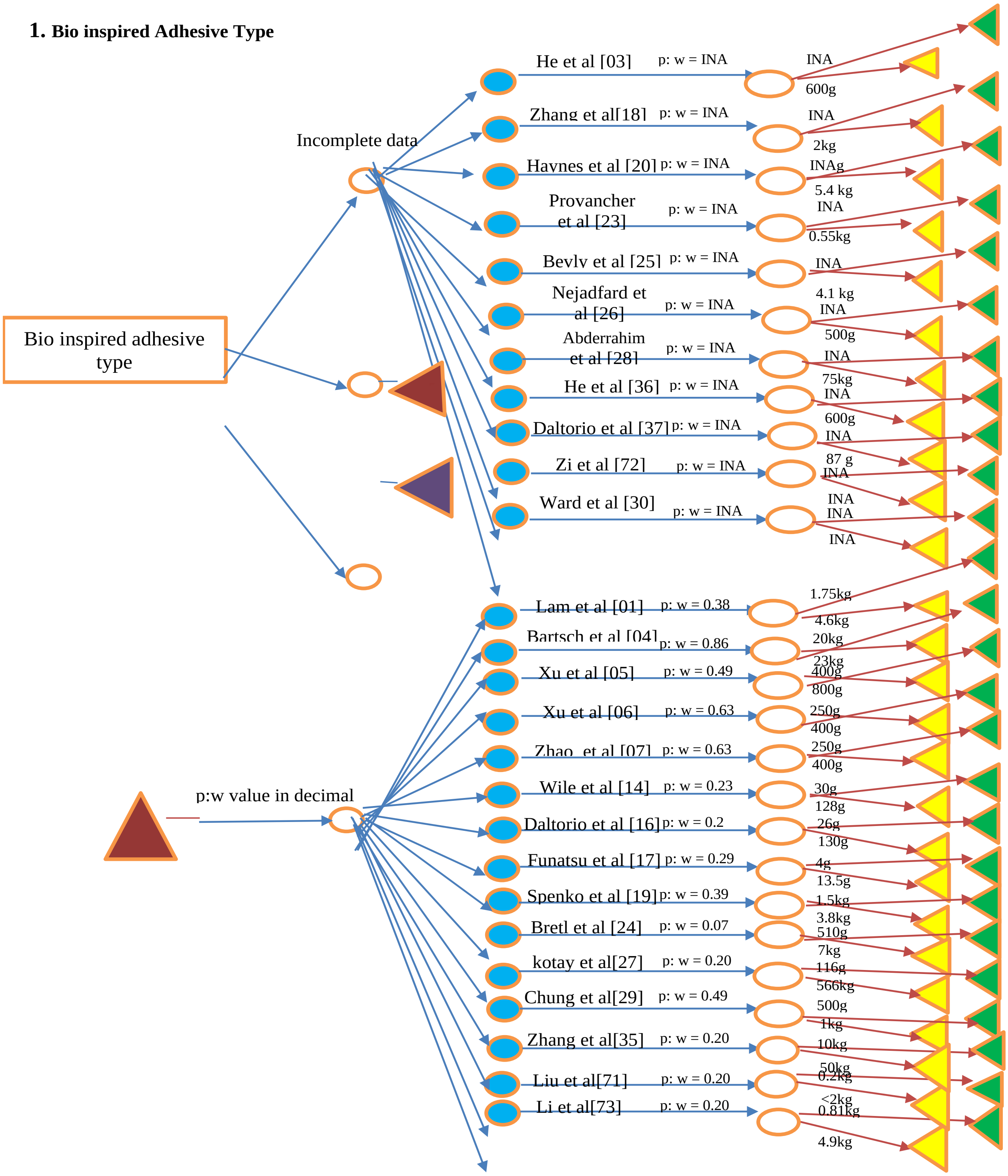
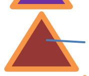
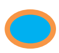
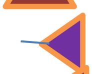
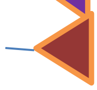



**Table1.** Decision Tree Analysis Symbol and its indication

| SNo: | Symbol | Indication | Symbol | Indication |
|---|---|---|---|---|
| 1 |  | weight |  | Transfer in p:w + ve integer branch |
| 2 |  | payload |  | Transfer in p:w decimal value branch |
| 3 |  | Author |  | Transfer to p:w +ve integer branch |
| 4 |  | Classification based on p:w value |  | Transfer to decimal value branch |

"Bioinspired robot " are those bot that replicates the motion of living beings or mimics the adhesive method like an worm, insects or any other creatures. An bioinspired robot mimicking how a bird or squirrels climbs the tree was proposed by Lam et al[01],this bot has claws to climb and it weighs 4.6kg with load carrying capacity of 1.75kg. An innovative method using grasping claws in bionic climbing robot weighs 431 g and has load carrying capacity of 1.3kg was proposed by Juan etal and Xu et al [02].The wet adhesive pad like that of insects were used in the bot proposed by He et al[03] which has self-weight of 600 g. A bio inspired six legged bot designed by Bartsch et al[04] weighs 23kg and has load carrying capacity of 20kg.An eight foot bot having payload of 400g and self-weight of 800 g was proposed by Xu et al [05] which is suitable for high altitude and tough surface. Xu et al[06] proposed bioinspired bot mimicking cockroach ,the bot weighs 400g and load carrying capacity 250g.Flexible pads and sprawling posture design was proposed by Zhao et al[07] in WCR with self-weight of 400 g and 250 load carrying capacity. The bioinspired bot replicating animal Tokay gecko was proposed by Carlo et al[08&09].This bot has 80 g for both mass and payload. Menon et al and Murphy et al[10 -12] developed a bot replicating the motion of lizard under Van dr Waal's force. Though the bot has no payload capacity, it weighs 300 g. The next version [13] had self-weight of 85g and load carrying capacity of 100g. Screenbot consisting of spines made of mesh substrates weighs 126g and has load carrying capacity of 30 g was proposed by Wile et al [14]. Daltorio et al[15] came up with innovative joint that enable vertical to horizontal transition, this bot mimics the locomotion of cockroach with self-weight of 105 g and 0 load carrying capacity. Another bio inspired soft bot was introduced by Daltorio et al[16] which replicated the motion of insects, this bot weighs 130g and possess the load carrying capacity of 26g.Hooking claw wall climbing robot was proposed by Funatsu et al [17] which weighs 13.8 g and possess payload of 4 g. Passive vibrating attachment replicating caterpillar type bioinspired robot weighing 2kg was proposed by Zhang et al[18]. Hexedal RiSE robot weighing 3.8 kg and having load carrying capacity of 1.5kg was proposed by Spenko et al[19].The same was upgraded as RiSe V3 having self-weight as 5.4kg was introduced by Haynes et al[20]. A gecko type hexapedal bot with self-weight 15g and load carrying capacity of 100 g was proposed by Birkmeyer et al[21]. CLIBO (claw inspired robot) developed Sintoy et al[22] has same value for both self-weight and payload as 2kg.Another bioinspired bot consisting of serial chain ,pendular link weighing 0.55 kg was introduced bv Provancher et al[23].LEMUR IIb possessing three revolute joint weighs 7kg and has load carrying capacity 510 g for each limb was designed by Bretl et al[24]. The bioinspired LIBRA proposed by Bevly et al [25] consists of leg type locomotion and has self-weight of 4.1kg. A special bot weighing 500 g designed for dome inspection using particle swarm algorithm was proposed by Nejadfard et al [26]. An bioinspired inchworm type bot weighing 566 g with load carrying capacity of 116 g was designed by Kotay et al [27]. ROMA built on caterpillar concept weighs 75 kg was proposed by Abderrahim et al[28]. A novel gripper possessing wheels named MovGrip was used in bot having self-weight of 1 kg and load carrying capacity of 500 g developed by Chung et al [29]. Another inchworm caterpillar mimicking bot having both mass and payload less than 2kg was proposed by Ward et al [30]. An innovative bio inspired bot replicating caterpillar motion weighs 27.8 g and possess load carrying capacity of 2.7 kg was designed by Zhang et al[31]. Wang et al [32] introduced caterpillar like bot weighing 1.2 kg and having load carrying capacity of 5kg.Two gecko based lizard type bot used for inspection purpose having self-weight of 148 g and 356 g with load carrying capacity of 41 kg and 36 kg respectively was proposed by Shen et al[33]. Bioinspired bot with 5 links replicating gecko motion has self-weight of 922 g and load carrying capacity of 2000g was developed by Liu et al[34]. An innovative passive adhesive caterpillar bot weighing 50 kg and possessing load carrying capacity of 10 kg was designed by Zhang et al[35]. A bot replicating stick insects with arthropods with microstructure in wet adhesive pad weighing 600 g was introduced by He et al [36] The Mini Whegs Tm mimicking the gecko and insects enhanced by compliant adhesive support for climbing purpose developed by Daltorio et al[37] weighs 87 g.The decision tree analysis for bio inspired adhesive mechanism is shown in fig 2.

**Electro adhesive type**

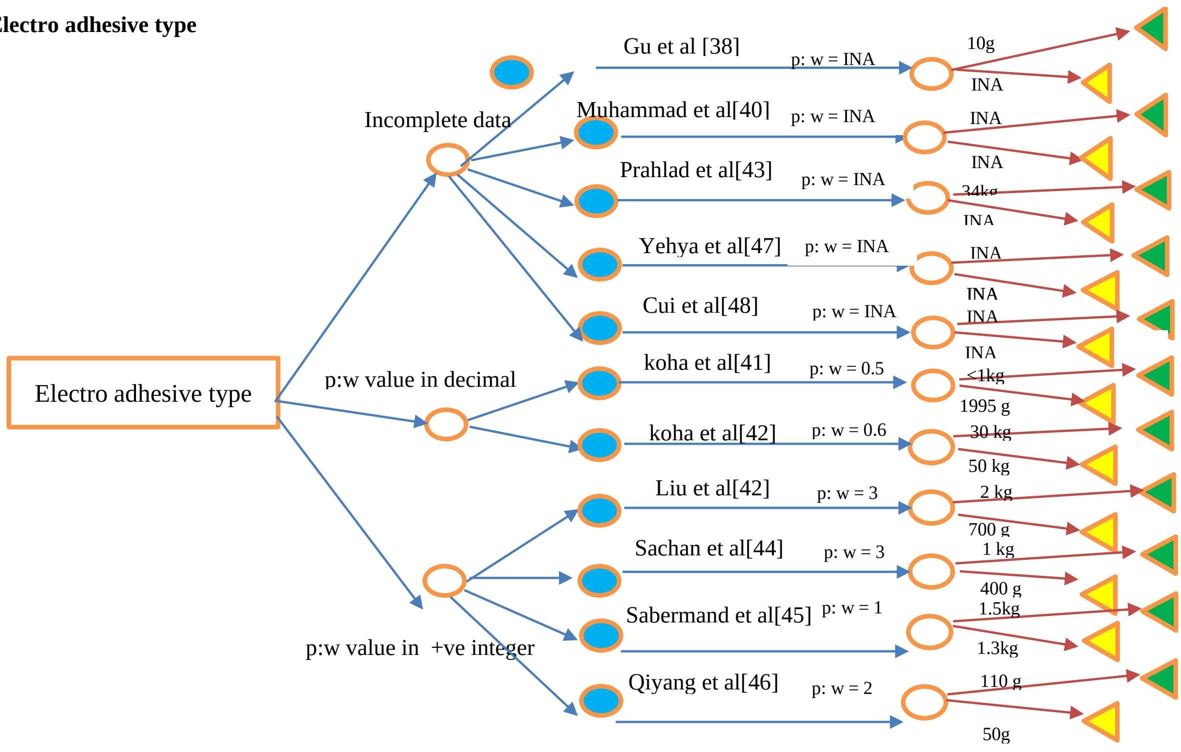
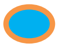



Fig 3. **Decision Tree Analysis of p:w in Electro Adhesive mechanism**

**Table2.** Decision Tree Analysis Symbol and its indication

| SNo: | Symbol | Indicates |
|---|---|---|
| 1 |  | weight |
| 2 |  | payload |
| 3 |  | Author |
| 4 |  | Classification based on p:w value |
| 5 | INA | Information not available |

There are very few papers with electrostatic adhesive mechanism in wall climbing robot. A soft robot carrying 10 gram payload while climbing glass, paper and wood was designed by Gu et al[38].An electrostatic adhesive wall climbing robot with 700 gram weight and 2kg payload was developed by Liu et al[39].Electro Adhesive with bipolar pads was suggested by Muhammad et al[40].Another electrostatic adhesive WCR named ELAD carrying payload less than 1 kg and having 1995 gram as self-weight was proposed by Koha et al[41].Another electrostatic adhesive type suitable for static fields and parallel plane was suggested by Koha et al[42] which has the p:w ration value as 0.6 with self-weight of 50 kg and payload capacity of 30kg.Prahlad et al [43] proposed a robo with payload of 34kg.The bot proposed by Sachan et al and Patil et al[44] can carry the payload of 1kg and has weight of 400 grams. Sabermand et al[45] designed an FFF electrodes which is suitable for rough shape wall carries a payload of 1.5 kg and weighs 1.3 kg. Paper and shape memory alloy (SMA) was proposed by Qiyang et ak [46] for the wall climbing bot that weights 50g and carries payload of 110 grams. Electro adhesion was used as clamping technique for bot by Yehya etal [47] with load carry capacity ranging between 12 to 15.5 kg. Electrically tunable adhesion for bot with load carrying capacity of 17.2 g./cm2 was proposed by Cui etal [48].

## 6.Rope and Rail Adhesive Type

SIRIUSc proposed by Elkmann et al[49,50,51] has rooftop gantry possessing power wires and cables was used for automated fascade sleaning at Faunhofer headquarters building. This bot has self-weight of 450 kg and gantry weight as 5000 kg. The bot with guided rails and DC motor at 3 different XYZ axis having mass of 6 lg and load carrying capacity of 15 kg was developed by Nansai et al[52] .A bot having rope ascender with 2 propeller thrusters having load carrying capacity of 4kg was proposed by Kim et al[53].A cable support with trolley crane roof top bot having mass of 60 kg was introduced by Qian et al [54].A Sky cleaner type RoboGlass bot weighing 146 kg & load carrying capacity of 55 kg consisting of rail mechanism along with rope support was developed by Wang et al[55].A bot with DCS based controller having CAN bus and sliding rods with rails and frames has self-weight of 100 kg and load carrying capacity of 89kg was proposed by Zhang et al [56,57].A novel sliding suction cup with network theory enhanced adhesive mechanism is used in bot introduced by Qian et al[58,59].An exhaustive study by Elkmann et al [60] on faced cleaning module resulted in Cleanant bot supported bv slack rope. Akinfiev et al[61] developed TITO 500 having self-weight of 200 kg used for cleaning vertical wall. Another bot having rope supported with mass of 400 kg used for cleaning wind turbine was proposed by Franko et al[62].A bot with guided rails having self-mass of 1.4 tonne was developed by Akira Matsumura et al [63] and his team members from Taisei corporation. Another bot based on rope and frames proposed by Rajesh et al [64] weighs 17-20 kg. Roboclimber developed by Ceoplina et al [65] has rope support regulated on winch. CLIBOT developed by Schober et al [66] possess claws used for climbing rope. A Bot supported by balloon and rope developed by Elkmann et al[67] possess self-mass and load carrying capacity of 50 kg put together.

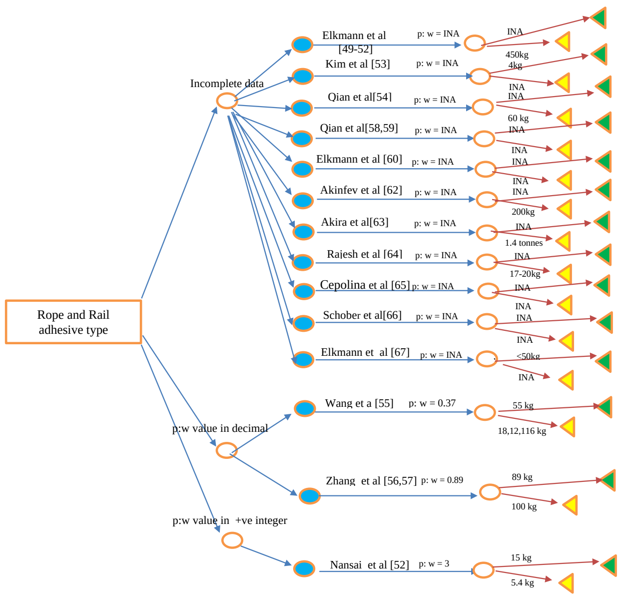
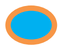



**Table 3.** Decision Tree Analysis Symbol and its indication

| SNo: | Symbol | Indicates |
|---|---|---|
| 1 |  | weight |
| 2 |  | payload |
| 3 |  | Author |
| 4 |  | Classification based on p:w value |
| 5 | INA | Information not available |

### 7.Chemical Adhesive

An active tail based bot named Vytaflex-10 consisting of sticky elastomer polymer as adhesive mechanism was proposed by Seo et al [68], the bot has mass of 180 g and load carrying capacity of 500 g. Another bot developed by Unver et al [69] having flat elastomeric tacky pads possessing 16 legs for locomotion weighs 100 g and carries the load up to 200 g. A novel magnetorheological fluid based bot having self-mass less than 1 kg and load carrying capacity of 75 g was proposed by Wiltsie et al [70].

<75 g

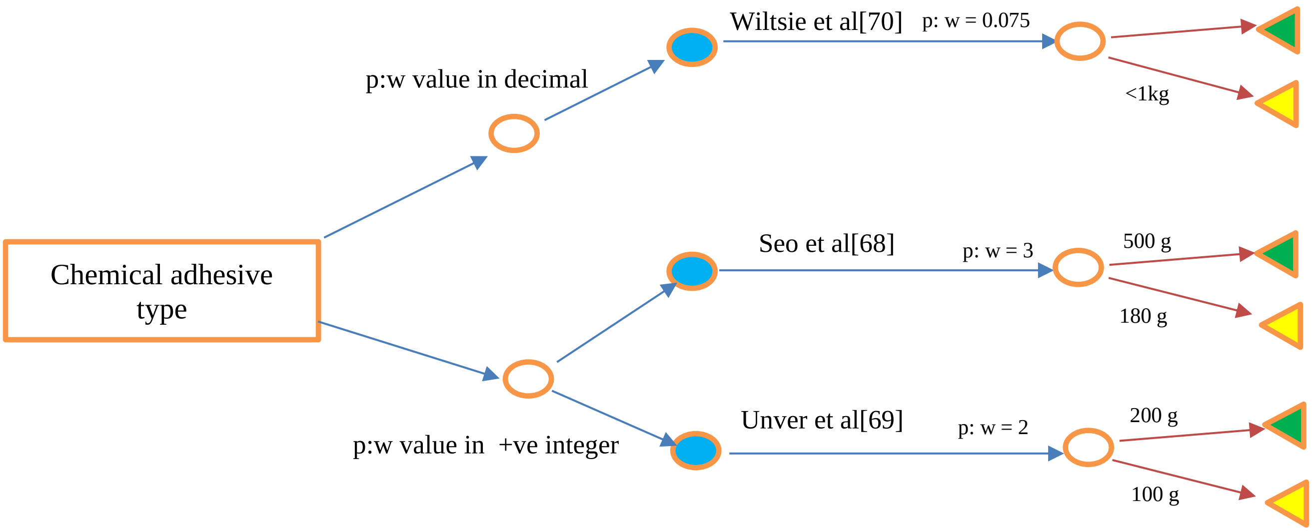



**Fig 4.** Decision Tree Analysis of p: w in Chemical Adhesive mechanism

**Table 4.** Decision Tree Analysis Symbol and its indication

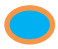
| SNo: | Symbol | Indicates |
|---|---|---|
| 1 |  | weight |
| 2 |  | payload |
| 3 |  | Author |
| 4 |  | Classification based on p:w value |
| 5 | INA | Information not available |

**Table 5 .** Comparison of count of Adhesive mechanism with respect to +ve p:w value

| SNo: | Type of Adhesive | Count of papers taken for survey | Count of papers having +ve integer value for p:w |
|---|---|---|---|
| 1 | Bioinspired | 41 | 11 |
| 2 | Electro adhesive | 11 | 4 |
| 3 | Rope and rail | 19 | 1 |
| 4 | Chemical adhesive | 3 | 2 |

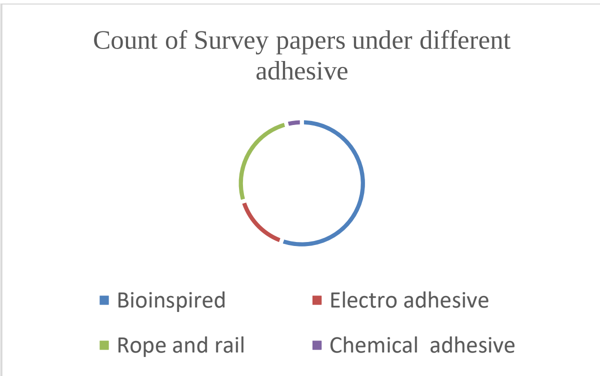



**Fig 5.** Count of survey papers under different adhesive mechanism

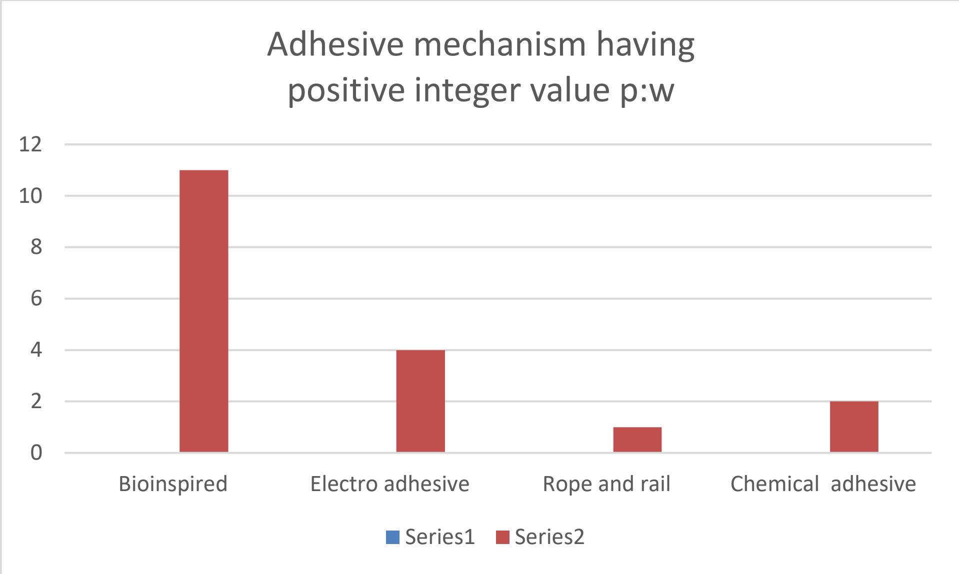



**Fig 6.** Types of Adhesive mechanism with positive integer p:w value

## 8. Conclusion

The fault tree Analysis emphasized on the key design attribute of a wall climbing robot which is payload and weight of the bot. Further to which by performing Decision tree analysis helps us to understand the p:w value of existing wall climbing robot under various adhesive mechanism. Out of the exhaustive survey (table 5) comparing the bioinspired, electro adhesive, rope and rail and Chemical adhesive method, it is found that more work is done on Bioinspired (fig 5) and that is the one having more number of positive payload to weight ratio (p:w) compared to the rest of the methods (fig6). This helps the reader to understand the existing mechanism and how to propose a novel adhesive mechanism improving the performance of the wall climbing robot compared to the existing one.

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