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THE DESIGN AND CONSTRUCTION OF A LOCALLY SOURCED ELECTRIC POWERED STAIR CLIMBING TROLLEY

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Abstract: Buildings with staircases have grown significantly as a result of improvements in building or home structures, and the strain associated with carrying items cannot be ignored. High levels of strain are related to the movement of loads along staircases, particularly in high-rise buildings. In order to make it simple to transfer large goods up and down stairs, this project concentrated on designing and building an electric-powered staircase climbing trolley from locally sourced materials. Everyday needs in our society drive the necessity for such a system. This robotic trolley is also employed to reduce the strain associated with lifting while on level ground and over a staircase. Given this, the project aims to design, build, and test the functionality of an electric-powered stair climbing trolley that can transport items up and down the stairs as well as on flat surfaces and even rugged terrain. The trolley uses a triple interlink wheel configuration that makes it simple to move things. When comparing the designed and constructed motorized trolley machine established in this work to the hand trolley, whose performance efficiency ranges from 50% to 60% as explored in previous literature, the motorized trolley machine performed 87% more efficiently. Moving products up and down a staircase can potentially be solved with the help of a motorized trolley that was designed and manufactured specifically for this purpose.

Keywords: Buildings, Locally sourced materials, Performance efficiency, Trolley

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1. Introduction

The need for space utilization and accessibility is becoming increasingly important in Nigeria today as both rural and urban settlements experience population growth. In particular, in urban settlements, which are at the center of the nation's economic life, land purchases are expensive and the need for multi-story buildings and skyscrapers cannot be overstated or undervalued (Ashish, 2015). The staircase is typically one of the first essential components to be named when listing the main components of a building design. The placement of a staircase inside a new building's layout is usually a crucial choice because it frequently affects how the entire property is laid out. Stairs serve as a straight-forward and convenient means of going from one level to another (Jay and Praveenra, 2016).

Various researchers have conducted numerous experimental investigations on vehicles for ascending stairs, such as trolleys, lorries, wheelchairs for the disabled, forks, etc., because of the advancement in building or home construction and the large growth of buildings with staircases (Praveen Raj et al., 2021). It necessitates a thorough investigation of the maximum load a cabin can withstand and how stress affects wheel alignment. A hand truck that climbs stairs with less effort was invented and manufactured which is beneficial for libraries, hospitals and ordinary goods carriers (Liu et al., 2005). The wheel frame was where this truck's major modifications were made. The maximum bending moment was computed for this mechanism, which was based on a stretched arrangement mechanism (Farhad, 2012). More than 90% of all staircases within this range are covered by an inclination of 44° to 45°, which has a significant impact on the transfer of load over the upstairs. According to the analysis of the literature, an optional maximum inclination warning alarm that warns the operator of an inclination greater than 44 degrees is present (Farhad, 2012). When a truck exceeds the limit, the appropriate safety measures should be implemented (Farhad, 2012). A stair climbing vehicle made by Hussain et al. (2022) uses a customized form of frame that moves across uneven terrain. In order to address a number of technical concerns with the vehicle's design, including its inability to maintain a high speed while climbing stairs, its wheel arrangement were placed into consideration during design and fabrication. According to Hussain et al. (2022), the sun, planetary, and idler wheels that are attached to the shaft as part of the frame arrangement must reduce the application of load. However, this study's main worry also relates to how steep the steps are (Hussain et al., 2022). For assistance while it travels over level ground, the vehicle has four sets of wheels. Three idler gears connect each wheel to the sun wheel. Ashish (2015) developed a four-wheeled robot that can ascend stairs at a height equal to its diameter. Due to the four differentially driven wheel configurations, it has a maximum gripping capacity and stability while moving over uneven terrain. According to Raj et al. (2018), the designed structure and mechanism included stair climbing capabilities. The major component parts of this product include modules like the seat, linkages, and frame. The seat's dimensions took anthropometric data into account. Focus was placed on a variety of factors, including the product's form, utility, technology, and architecture by creating digital mockups of various elements created in PRO-E Creo software and integrated to represent the designed form of the product (Marathe. 2016). In the virtual environment of the PRO-E Creo program, the necessary simulation of the products was created. Here, the ABS (Acrylo Butadiene Styrene) material was employed to fabricate the wheel carriers utilizing RP (Fused Deposition Modelling). After gathering customer needs from various sources, the wheel chair was added with some extra features, including an integrated common facility. A hand trolley was to reduce the strain associated with carrying loads while standing on level ground (Pratik el al., 2020). However, when it comes to carrying the load over a staircase, these technologies typically fail. The major goal of the project is to develop a practical and user-friendly way of moving heavy goods up and down stairs while requiring the user to exert the least amount of effort possible (Virag et al., 2022). In this project, a motorized trolley with trilobed wheel frames on both sides of the climber was built. Each trilobed frame had three wheels. A gear-motor system was used to turn the wheel assembly, and a DC gear mesh was employed to slow the wheel's rotation. The DPDT switch was connected to the motor using a lead acid battery with a comparable rating (Raj et al., 2018).

This study therefore focused on the design and construction of a locally sourced electric powered stair climbing trolley.

2. Materials and Methods

2.1. Design Concept of Motorized Staircase Climbing Trolley

The electric stair climber trolley is full of innovative features that make moving products or packages simple and efficient. With a charging system to keep the cell (battery) charged when it runs out, this idea essentially consists of an electric motor for rotating the chain and a gear system attached to the shaft of the tires, which makes it possible for the tires to rotate. Due to its noiseless mode of operation, it has been adopted by various homes, businesses, or industries for moving heavy objects. The electric-powered stair climber utilized in this study is reinforced with a robust, foldable steel frame that makes it easier to lift and manipulate stairs by securely holding the burden and facilitating a quick and easy transaction.

2.2. Design Considerations and Factors

Numerous aspects were taken into account when designing this system in order to achieve the desired results. For example, if loads or items can be moved up or down stairs with ease, more people will be interested in using them for this purpose Alaspure et al. (2016). The following are the design considerations.

1. Cost: After doing a market study, the materials and other essential parts for the design idea were determined.
2. Safety: When the machine is operating, whether engaged or loaded, this element takes safety into account.
3. Functionality: This refers to how well the machine performs when loaded or engaged.
4. Efficiency: The system's capacity to complete its tasks without error was also taken into account. The motorized trolley's efficiency was determined using Equation 1

$$\text{Efficiency of Trolley} = \frac{\text{Work output}}{\text{Work Input}} \text{x} 100\% \quad (1)$$

2.3. Concept Chosen in this Project

Due to its present relevance in terms of energy applications, manageability, and stress-free control, this concept was selected. The wheel-frame, wheel, shaft, gear, motor, battery, and bearing are the major elements used in the design of the motorized stair climbing trolley.

2.4. Material Selection and Fabrication

The fabrication of the trolley begins with the fabrication of quasi Tri-Star frame setup. Various links are joined together using welded and bolted joints.

2.5. Components/Materials

Components/materials are presented below;

1. Tri star wheel
2. Battery
3. Wheel holder
4. Gear motor
5. Supporting frame
6. Bearings

2.6. Description of Components

2.6.1. Tri – star wheel arrangement

The Tri-Star is a revolutionary wheel design with three wheels arranged in an upright triangle, two on the ground and one above them. It was created by Robert and John Forsyth and given to Lockheed in 1967 (Shriwaskar and Choudary, 2013). The entire system turns over the obstacle if either of the wheels in contact with the ground becomes stuck (Figure 1).

2.6.2. Battery

Any family of devices that directly convert chemical energy into electrical energy is referred to as a battery in the fields of electricity and electrochemistry. Although a single cell of this type is frequently referred to as a battery, a battery is actually an assemblage of two or more galvanic cells capable of such energy conversion. In this study, a 12 volt 100Ah battery was employed.

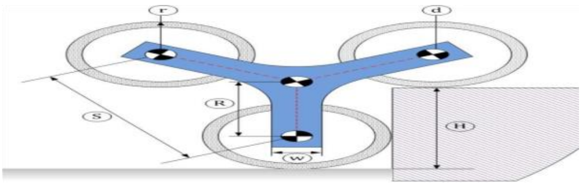

Figure 1. Wheel arrangement of a motorized staircase trolley.

2.6.3. Gear motor

A gear motor combines a motor and a gearbox into one unit. When a gear head is added to the trolley, the speed is decreased but the production of torque is increased. The three most crucial gear motor performance factors are speed (rpm), torque (LB-IN), and efficiency (%).

High torque output

The torque of a geared motor of the fabricated trolley was multiplied by the gear ratio and gear efficiency when one it was utilized. An ungeared standard motor will produce less operating and holding torque than a geared motor (Figure 2). Along with increased torque output and strengthened stiffness, numerous additional advantages can be attained, including motor torque times the gear ratio times the gear efficiency is the geared motor torque. When a specific gear ratio is exceeded, the line flattens out since most gearheads have a maximum torque limit.

Figure 2. Gear used in the motorized staircase trolley.

2.6.4. Supporting frame

A rigid framework made of beams (rafters, posts, struts) is used to support other constructions like staircase trolley, bridges and roofs.

2.6.5. Design of shaft

Shafts used in this study were created using a combination of stiffness and strength. To ensure that any stress on the shaft does not exceed the material yield stress, it is designed based on strength (Figure 3).

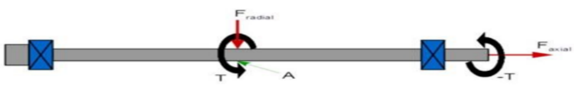

Figure 3. Designed shaft.

2.6.6. The bearing shaft

A shaft bearing, also known as a cutless bearing, is the last part of the drive train that is located forward of the propeller. It is a rubber-lined composite brass bearing through which the propeller shaft rotates.

2.6.7. The roller chain

In various types of home, industrial, and agricultural machinery, such as conveyors, wire-and tube-drawing machines, printing presses, cars, motorcycles, and bicycles, roller chains or bush roller chains, are the type of chain drive that is most frequently used to transmit mechanical power.

Types of roller chain

Standard, heavy duty, double pitch for small loads, attachment choices, and several application-specific geometries are among the different types of roller chain (Figure 4).

Figure 4. The roller chain.

2.7. How does this Project Work?

A stair-climbing truck is a piece of manual material-handling equipment that can securely transport items up and down stairs with the least amount of human effort. It operates on a similar principle to that of a straight forward screw jack. Here, a nut and a lead screw assembly were used to power up and down the weight that is put on the platform. The lead screw, which is fastened to the main frame, is only permitted to revolve in one direction: centrifugally. The nut, which is attached to the second frame, moves along the lead screw while being restrained from rotating. A battery is attached to a high-torque motor, which in turn powers the lead screw. The equipment is always fully within the operator's control.

2.8. Mechanical Design using CATIA

The tri-star wheel trolley in this study was created with CATIA P3 V5 R11. CATIA is a multi-platform mechanical design suite. It is a parametric solid modeling design tool with characteristic-aided support. Phases supported by CATIA include conceptualization, design, engineering, manufacturing, and PLM. Due to its user-friendly graphical user interface, CATIA makes it simple to convert 2D sketches into 3D parts. Complete 3-D replicas are built with or without limitations by employing automatic or user-described relations to restrict design objectives. The various elements employed in this design include Pad, Pocket, Revolve, Rib, Slot, Loft, etc. to conduct operations like add, remove, rotate, sweep, and cut the material while modeling (Praveen Raj et al., 2021).

2.9. Fabrication Process of the Staircase Climbing Trolley

1. Purchase of construction materials
2. Making out and cutting of construction materials

3. Machining / machine tools process
4. Assemble of fabricated and purchased components
5. Surface finishing
6. Painting/spraying painting/coasting metal treatment (Figure 5, 6)
7. Testing evaluation, installation and.

Figure 5. An assembled motorized staircase trolley.

Figure 6. Pictorial view of the tri-stair wheel during fabrication.

2.10. Performance Traits

The machine was also tested for other traits of performance such as:

2.10.1. Efficiency

This is the ratio of the useful work (output work) completed by a machine to the total work input; work output is equal to work input. This is also the case when the device effortlessly performs the task at hand.

2.10.2. Durability

A performance testing method called the durability test was used to identify a system's characteristics over time and under diverse load circumstances. During this test, it was determine whether transaction response times are consistent over the course of the test.

2.10.3. Strength

This test determines a machine's material's tensile strength as well as how far it can be stretched before it breaks or reaches its limit.

3. Results

3.1. Determination of Basic Dimensions

The basic external dimensions were considered based on literature survey only (Liu et al., 2005). The designed model has the dimensions which are calculated based on the step size (height and width) where the fabricated model is tested. The design of the staircase trolley is modeled to allow others to use stairs at once. The following were the basic dimension used.

- The external diameter of the solid shaft is taken as 25 mm.
- The length of the shaft is 825 mm.
- Two pairs of Quasi-static frames and a total of six rubber wheels are used (Murray, 2003)
- The diameter of wheel is taken as 120 mm for suitable dimensions of the stairs which is about140-150 mm in height and 300-350 mm in depth.
- The inter-lobe angle of Tri-Star clamp is assumed as 120°
- The distance between the centers of two wheels was taken as 190 mm.
- The distance between two wheel frames is taken as 635 mm.

3.2. Tri-Star Wheel Design Calculation

The position of the Tri-Star wheel on the stairs affects how the wheel characteristics are determined as shown in Figure 7, it is dependent on two factors; the distance between the edge of the wheel on the lower steps and the face of the following stair (L_1) and the distance between the edge of the wheel on the top stair and the face of the following stair (L_2).

By comparing these parameters three states may occur as follow: $L_1 < L_2$; $L_1 > L_2$; $L_1 = L_2$

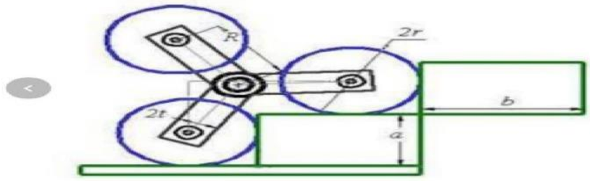

Figure 7. The five parameters on tri-star wheel.

In the design of the Tri-Star wheel, five factors are crucial: the height of the stairs (a), the width of the stairs (b), the regular wheel's radius (r), the Tri-Star wheel's radius, the distance between the center of the Tri-Star wheel and the center of its wheel (R), and the thickness of the holders (2t) that secure the wheel in place on the Tri-Star wheel. According to the project requirement, the value of (a) and (b) are determined as a = 20 cm, b = 25cm, r = 5cm and the Distance between frame center and wheel center is given in Equation 2.

$$R = \sqrt{\frac{a^2 + b^2}{3}} \tag{2}$$

$R = \sqrt{\frac{20^2+25^2}{3}}$= 17.569 =18.484 cm.

The minimum value of the radius of regular wheel (r_{min}) to prevent the collision of the holders to the stairs was calculated using Equation 3;

$$r_{min} = \frac{6Rt+a(3b-\sqrt{3a})}{(3-\sqrt{3a})a+(3+\sqrt{3a})b} \text{ where t = 1} \quad (3)$$

$$r_{min} = \frac{6 \times 18.484 \times 1 + 20(3 \times 25 - \sqrt{3 \times 20})}{(3-\sqrt{3a}) \times 20 + (3+\sqrt{3}a) \times 25} = 10.135 \text{ cm}$$

The maximum value radius of the radius regular wheels (r_{max}) to prevent the collision of the wheels together was obtained using Equation 4.

$$r_{max} = \sqrt{\frac{a^2+b^2}{2}}$$
$$r_{max} = \sqrt{\frac{20^2+25^2}{2}} = 22.64 \text{ cm} \quad (4)$$

The maximum value of the thickness of holders ($t_{1.max}$) to avoid the collision between the holders and stairs was obtained using Equation 5

$$t_{1.max} \frac{ar(3-\sqrt{3})+br(3+\sqrt{3})+a(\sqrt{3a}-\sqrt{3b})}{6R}$$
$$t_{1.max} \frac{20x5(3-\sqrt{3})+25x5(3+\sqrt{3})+20(\sqrt{3x20}-\sqrt{3x25})}{6x18.484} = 4.915 \text{ cm} \quad (5)$$

Furthermore knowing the amounts of r and R, we can derived the maximum height of stairs that the robot can pass through was calculated using Equation 6;

$$a_{max} = \sqrt{a^2+b^2-r^2}$$
$$a_{max} = \sqrt{20^2+25^2-5^2} = 31.622 \text{ cm} \quad (6)$$

For traversing the stairs with maximum height derived above, the half thickness of the holder must be in the following range (Equation 7):

$$t_{2.max} \frac{r(r+\sqrt{3(a^2+b^2-r^2)})}{2\sqrt{a^2+b^2}}$$
$$t_{2.max} \frac{5(5+\sqrt{3(20^2+25^2-5^2)})}{2\sqrt{20^2+25^2}} = 4.667 \text{ cm} \quad (7)$$

Regarding to the limit that have been derived for t and the point $t_{2.max}$ is less than t_{1max} and to fulfil both condition of not colliding of the holder with the stairs and traversing stairs with the maximum height derived before, it is only necessary that the t to be in $t_{2.max}$. Orthographic view of the staircase climbing trolley was given in Figure 8.

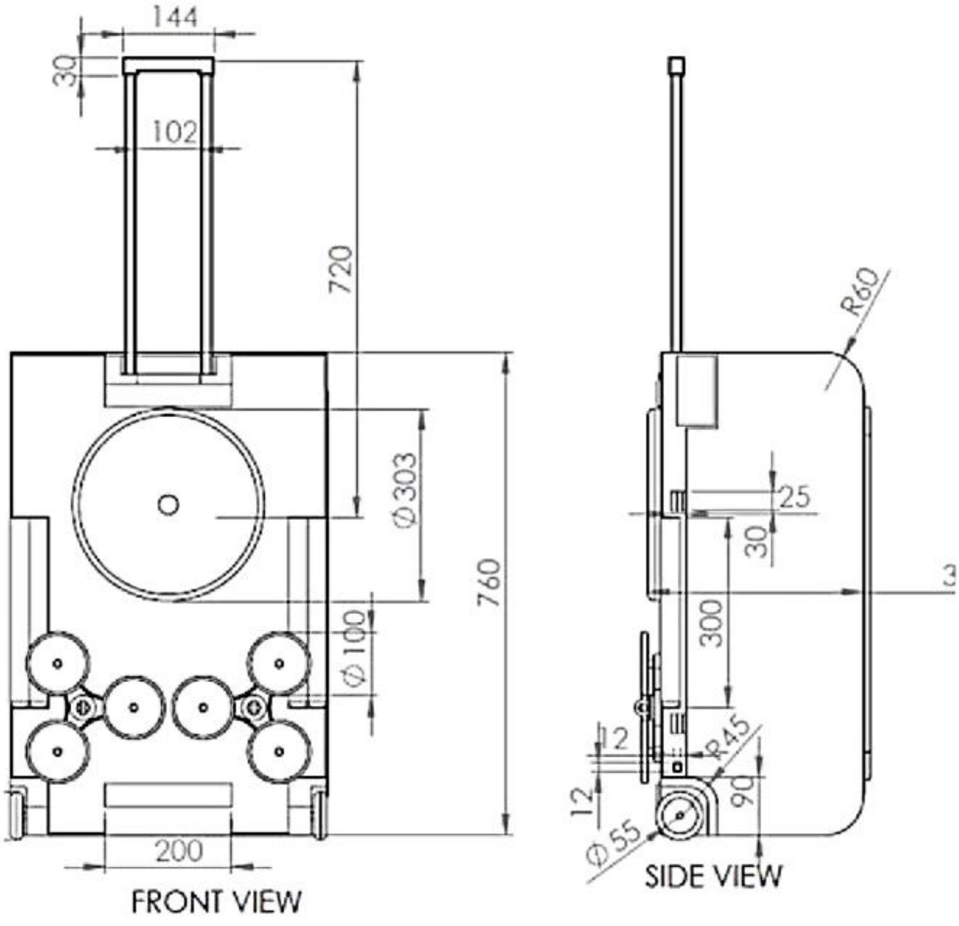

Figure 8. Orthographic view of the staircase climbing trolley.

3.3. Test and Performance

The electric powered trolley moved smoothly over the staircase. The trolley also moved uniformly on a flat surface without any issues, and as it climbs the staircase, there is no difference in speed between steps. On a flat surface or stairway, the machine was found to emit relatively little noise and vibration. Additionally, it was noted that the machine became agitated when it encountered steps of various sizes. The size and shape of the wheel frame caused such agitation, although it is uncommon to find different step sizes in a building. On identical-sized steps, the machine performed admirably. The machine's test run revealed that it operated on stairs at an angle between 30 and 60 degrees. Although the machine's smooth ramp angle could not be determined, it is clear that the stair inclined angle is smaller than the ramp angle.

4. Discussion

The weight of the fabricated trolley is 15.5kg. The wheels were held together by the Tri Star wheel Frames. The wheels were attached to each of the frame's arms, and the Tri-Star arrangement spins as it approaches the stairway's edge. Oxy-fuel gas cutting, grinding, drilling, and boring are among the processes used in the construction of the Tri-Star frame configuration. Although it is simple to make a straight wheel frame, a quasi-static wheel frame was chosen with a 50mm radius curve in between two arms to give the wheels strength and stability. The angle between the two wheel axes was also chosen at 120^0 for smooth operation. The maximum thickness is maintained as 5mm. Stainless steel with high chromium and low carbon content was selected in order to minimize corrosion and carbide precipitation due to welding. The design of the Tri-Star wheel frame, which binds the three wheels together, is depicted in the following picture according to its measurements. The project's primary job is the alteration of the wheel frame (Mogaddam and Dalvand, 2005). It is tiresome to ascend stairs with a single wheel. As it climbs the stairs, the tri-wheel configuration turns in accordance with how the wheels are positioned in relation to the frame. For the trolley body, mild steel was chosen rather than iron since it has more versatile material features. Mild steel has a density of about 7850 kg/cm^3 and a Young's modulus of 210 GPa. Mild steel is affordable and malleable despite having a relatively low tensile strength. As a result, the handle and body are made from mild steel metal pipe with a circular cross section and a one-inch diameter.

The trolley moved at a steady 20 rpm over a flat surface, and there was no speed difference when going up or down stairs. It was observed that there was relatively little noise and vibration on a level surface or staircase. The trolley appeared to be under stress as it approached a stairway with different step sizes. The size and shape of the wheel frame were the major causes of this. As a result, this automated staircase trolley can be used for a variety of staircase sizes. Nevertheless, different step sizes are not typically included in building designs. When the step size was uniform, it demonstrated strong performance. Here in this project, a separate frame may be utilized to move over stairs of various sizes and shapes, making it useful for a variety of stair sizes. The vehicle's test run revealed that the highest stairs with a maximum 45° gradient was the height the vehicle could climb. It would be impossible to climb the stairs if the inclination was greater than 45 degrees. Few staircases with an inclination higher than that angle are typically accessible in building construction. The vehicle's smooth ramp angle (s) was not provided. However, it is obvious that the stair inclined angle is smaller than the ramp inclined angle. It was observed that due to the wheel frame's larger radius being used to ascend the stairs, the vehicle's velocity while doing so was higher than it would have been on a flat surface. The car was moving up the stairs at a 55 in/hr speed. The speed of the car moving up a ramp, however, was not recorded. There should be no difference between this speed and the speed on the horizontal surface. The explanation above can be summarized by saying that, despite its drawbacks, the vehicle was a good substitute for utilizing stairs to move cargo.

5. Conclusion

During testing, the main goal of supporting a heavy weight of 120–140 kg is accomplished. When the straight frame was tested for different step sizes, the performance was a little more challenging. However, the automated trolley performed better even for steps of varying sizes when tested with a quasi-static frame. The results of a static structural analysis show that it can move large loads with little distortion and without breaking. However, using it on stairways, elevations, and uneven surfaces is highly ergonomic. It is effective, affordable, and simple to put together, this why it is suggested for handling materials. The machine's benefits include the simplicity with which heavy items of furniture and luggage can be moved from one floor to another. Bricks of various kinds and sizes are light and portable, making them ideal for construction sites. With consistent steps, the trolley's overall performance is seen to be strong. The frame and wheels cannot break under typical conditions because of how safe the design is. According to the tests that were done, the stair climbing trolley can support a load of 100 kg on a flat surface. It has the ability to climb a 45-degree stairwell while towing a 50-kg load.

Author Contributions

The percentage of the author(s) contributions is present below. All authors reviewed and approved final version of the manuscript.

	D.D.O.	M.A.	J.J.	O.O.A.
C	100			
D	25	25	25	25
S	100			
DCP	25	25	25	25
DAI	25	25	25	25
L	25	25	25	25
W	25	25	25	25
CR	25	25	25	25
SR	70	10	10	10
PM	100			
FA	25	25	25	25

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

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