Wheelchair Climbing Construction for Industrial Logistical Applications

Bernhard Heiden\textsuperscript{1,2}, Daniel Kattnig\textsuperscript{1}, Julia Pechmann\textsuperscript{1}, Volodymyr Alieksieiev\textsuperscript{1,2}, Bianca Tonino-Heiden\textsuperscript{3}

\textsuperscript{1} Carinthia University of Applied Sciences, Industrial Engineering Studiengang, Europastrasse 4, 9524 Villach, Austria
\textsuperscript{2} Institute for Mechanical Engineering and Transport, National Technical University 'Kharkiv Polytechnic Institute', Kyrpychova 2, Kharkiv, Ukraine
\textsuperscript{3} University of Graz, Heinrichstraße 26/V, 8010 Graz, Austria

b.heiden@cuas.at

Abstract. The human condition is - ever since becoming, in an evolutionary sense, human-associated with running on two legs. Only in the latest human technical development, stairs have become increasingly present as they crystallize to be more suitable as an artificial environment. Although stairs are suitable for humans without walking handicap, they are not for wheel-driven vehicles, like Automated Guided Vehicle (AGV) in industry or personal accompanying support vehicles as an example. In this mixed human-machine environment a sort of stair climbing is essential for many logistic applications, as this is an, from the mechanical engineering point of view, essential step in mechanization and their automation. Only recently, a stair-climbing device has been issued a patent, called the “Malteserrollstuhl”, which is designed for stair climbing for handicapped people. This patented mechanism could be further used for industrial applications. The goal of this work is to investigate the possible future directions and strategies that are most likely to be implemented, on the base of this patent, as the next steps towards logistical industrial applications.

1. Introduction
The human condition is - ever since becoming, in an evolutionary sense, human-associated with running on two legs. Only in the latest human technical development, stairs have become increasingly present as they crystallize to be more suitable as an artificial environment. Although stairs are suitable for humans without walking handicap, they are not for wheel-driven vehicles, like Automated Guided Vehicle (AGV) in industry or personal accompanying support vehicles as an example. In this mixed human-machine environment a sort of stair climbing is essential for many logistic applications, as this is an, from the mechanical engineering point of view, essential step in mechanization and their automation. In times where postal and delivery service providers are constantly struggling with lowering margins in the market, it is getting more important to design processes lean and efficient. Furthermore, the availability of reliable and capable workforce in this sector more often proves a bottleneck because, though it is a physically demanding task, not well paid. Therefore, the substitution of the labor force with technology could be interesting for companies operating in this sector. Hence, the possible application of the “Malteserrollstuhl” (Malteser-wheelchair) in logistics processes will be investigated within this paper.
The objective of this work is to investigate, the systemic novelties of the patent application “Malteserrollstuhl” [1], and to give a prospect of how this could be integrated into logistical industrial applications.

First in the section “Systemic Analysis” we go deeper into what are machines, what are they for in general, and what of some in the context special important properties can be seen for transport-machines. Second, in the section Malteserrollstuhl (Malteser-wheelchair), we investigate the Malteserrollstuhl, its development-steps, and its basic function as well as how it can be embedded in a systemic environment of stair-climbing and its relation to general system properties, as is with forces of construction variants. Third, in the section “Industrial Logistical Applications” we look at the actual arising industrial applications and markets that can be impacted by the Malteserrollstuhl-principles and its further transport vehicle integration. Finally, we make a summary and give an outlook for future application and mechanical engineering pathways for wheel-chair vehicle automation in the context of this work.

2. Systemic Analysis of the question: “What is a machine for?”

In this section, it will be analyzed what a machine is for and how it can be accomplished for it to be a defined goal for somebody.

2.1 Precondition – The All-Around Point of View Point (AAVP)

What is an All-Around Viewpoint? A standpoint from which everything is seen, or can be seen or could be seen. Wittgenstein introduces a thought [2,§352], to the sentence of the excluded third party in logics, that “we cannot turn our gaze away from this image.” He means that once we believe that this sentence exists and that the principle of the excluded third party applies, and we believe this, we cannot turn our gaze away. But there are other views and points of view possible and these are then just different theories and then e.g. with these this sentence is not applicable yet. So we have to revise our first theory, or we look at it from the All-Around View Point - AAVP.

2.2 A Machine Regarded as a System – Conficiency and the All-Around Point of View.

A machine can be regarded as a kind of tool a means like a hand is a means to build a tool. The tool itself is then a means for further tools ad infinitum. What we regard in human evolution is that together with the development of the brain about threefold in mass in about 3 Mio years from the ape brain, humans evolutionary natural tool, the hand, coevolved by differentiating his fine motoric. This is now called the pinch grip - two fingers are used like with a gripper - of humans, which allows him to hold a pencil and write and many other useful things (q.v. [3]).

A machine - an application - is an instrument, is a means, is a limit, a border, which can be interpreted according to Spencer Brown [4]. But is this really true? Let us make a thought experiment: “I see the world without a machine. Then I see the world with a machine. E.g. I drive a car and see simultaneously the world as I drive.” This makes the difference, with and without the machine. The machine changes my subject view of the world, in this example. Therefore it is a border that I am looking through like through a window. It is between me and the world. Therefore it is a means.

“I see the world with a machine and so the world is changed”, one might say, “The machine is a means by which I see the world.” another could say. So the machine itself is a limit. The machine is a border to the world. Another machine is then another border to the world.

A machine that is more permeable to the world is more confident than other machines (compare Figure 1). That can be also interpreted by giving more specific possibilities, concerning persons, subjects, and the environment.
The universal virtual classroom, or the practical application of remote teaching, can be regarded as another machine [5]. It is more permeable, more confident than other machines. It appears transparent as in the extended picture in Figure 2. This gives the transparent orgiton image. An orgiton is here an elementary cybernetic unit of mass, energy, and information [6]. “Look at the class as parents, then the teachers, the school looks at your private”. The transparency applies in both directions. The machine the "virtual classroom" is a tool that increases the "conficiency".

That everything is connected is the prerequisite. The edges – according to graph theory, a system that can be described by edges and nodes [7, 8] - are the precondition that conficiency happens. The edges, in this case, are e.g. the flow across the boundary (compare also Figure 1). They are a necessary condition. Like a lower generation orgiton is the precondition for the next, as is the case in an information feed-back cycle [9].

![Figure 1](image.png)

**Figure 1.** The all-around point of view (AAVP) with views A and B. The world is transparent for a subject using a machine, means, application. It is differently transparent compared to B. The fine structure of the machine produces a changed perception. The subject is always in his world with his point of view. The border to the world is the means. Different means have different configurations. To be an all-round point of view, the world must become more transparent, the machines must guarantee this in a form. Is A more transparent than B? That depends. If transparency is the transmission of linearly directed rays, then A is more mediated than B. But it is also possible to imagine a "pathway" which is curved and therefore less mediated than in B. This means that the machine is a means that is differently efficient in relation to different subjects and their will to take a pathway. A machine is therefore a means of enabling a particular subject to find its way to the world. It is a potential space. Regarding it, there are many possible machines. Fewer of them are confident in the sense, that they allow people to interact.

The different orgitons (compare also [6]) express the interlocking. An orgiton is the combination of material, energy, and information into one elementary unit, that entails himself to the following generations. In the virtual classroom the transparency increases (see also Figure 1), which can be described with different transparent images (q.v. Figure 2).
Figure 2. Transparent orgiton model as an extension to [5]. Due to the transparency properties, the order structures are visible. Predecessor, successor, and the interlocking - the interlocking is the confluence in the material sense and the *conficiency* in the sense of social-togetherness. Each form (triangle, circle, square) can be regarded as properties related to matter, energy, and information. The borders depict the borders of the forms. Properties of conficiency can be accomplished by transparency or transmittance through borders as a picture of the process potentials, allowing for increasing interactions on different orgiton generation levels.

What decisive is, is the interaction, the efficiency. The “causa conficientis”. Through the interaction, a new order emerges which has only become possible through transparency. Parents, teachers, children work together in a new village on a path for the future. This is how one could describe the principle of conficiency.

2.3 Transport Orgiton (TO) or General Elementary Transport System (GETS).
In the all-around point of view (AAVP) a transport orgiton can be defined as a set of sentences – axioms - which allow for further extension:

1.) A transport orgiton is a machine M that moves in the World (W).
2.) M is a border relative to a subject S in AAVP.
3.) S is connected to M in a fixed way.
4.) Redundant and multiple-type inter-, intra-, and trans-border-connections increase *osmotic* (nonintentional subjects (objects)) and *conficient* properties of GETS potentially.

This system depends strongly on the subject's intentions. This can be interpreted as personal machines or user-centered machine-adaptations.

It is important to get these osmotic or confident properties of the border-connections. Applications to these are flexibility in usage, and stability due to redundancy, or stability. When applying e.g. stair climbing, then M is the border between W and S. More possible interactions mean broader distribution of how the points of center of mass are distributed, leading to the stabilization of vehicle transport properties.

3. Malteserrollstuhl (Malteser-wheelchair)
In this section, there will be provided a short history of the Malteserrollstuhl.

3.1. First Version of Malteserrollstuhl
The first version of the Malteserrollstuhl is depicted in Figure 3. There is an instability point for the last stair.
3.2. Second Version of Malteserrollstuhl
In Figure 4, the second version of the Malteserrollstuhl is depicted. It solves compared to the first version of the stair climbing by inversing Malteser-wheel by a “Schwinge” (wing).

Figure 3. Malteserrollstuhl in its first version according to [10]. In (a) the unfolded Malteserrad (Malteser-wheel) for the use in the plane is shown. In (b, c) the Malteserrollstuhl is climbing on the stair.

Figure 4. Maltserrrollstuhl in its second version according to [1]
This leads to the fact, that the big Malteser-wheel has not to be transformed like in version one. The only remaining “move” is the switching of the Wing. This then leads to an overall stable movement along the stairs which was demonstrated with a 1:4 model (see Figure 5).

3.3. Malteserrollstuhl – Aspects concerning Wheel Forces and Transportation Properties

One of the most important tasks of Malteserrollstuhl is a minimization of the human load. In addition to its use for people with walking handicaps, some of them can also be used for logistical purposes in industry, e.g. for the lifting of packages upstairs. The goal of this section is to investigate, how human load can be minimized using a distribution of mechanical forces.

When the Malteserrollstuhl goes upstairs, it performs a complex combined motion with variable velocity (see also [12]). In this case, the most important requirement for minimization of the human load is a minimization of peak loads. For this purpose, the dimensions and proportions of the chairs’ mobile parts have to be optimized as well as forces, which are involved in the lifting process, have to be considered. For this purpose, the building of trajectories of wheels’ teeth centers of mass and their subsequent analysis have to be done. From the statics law-axioms, points of force applications with the biggest tangential angle to the horizontal correspond to the maximum force value and vice versa. (sum of forces is constant). The solution is to create a bigger amount of trajectories for wheels centers of mass with variable wheels parameters (diameter, number of teeth) to determine its minimal angle to the horizontal. This investigation is shown in Figure 6 (instead of teeth a different amount of wheels was used).

In Figure 6 the trajectories of transposition of wheels centers of mass are shown, where the five “Malteser-wheels” block demonstrates the smallest angle to the horizontal in comparison to the three “Malteser-wheels” block. Hence is to conclude, that such a construction allows a relative minimization of the human loads mechanically.
4. Industrial Logistical Applications

In the following, some future industrial applications are reviewed. First, a critical analysis of the patent applications and related work [1, 10, 11] is done concerning potential future applications, indicating technical missing steps. Second a more detailed view of the situation of current Automated Guided Vehicles is given with more specific needs in this field to apply for stair climbing and similar gravity overcoming efforts for those transport applications.

4.1 Industrial Stair Climbing – Some Potential Future Applications – Critical Analysis.

Stair climbing technologies are to be found in the context of the transportation of heavy cargo through vertical borders with a person as operator [13]. However, several further projects and patents explore the application of this technology in other fields of operation, such as military and security applications [14] or rescue applications [15]. This technology could furthermore be of special interest for logistics service providers operating in the sector of small goods transport and/or parcel delivery. Especially in urban areas with a grand density of high buildings, the application of an autonomous stair-climbing robot could decrease the need for labor force within a fully automated process. The feasibility and efficiency of that use case are subject to the Master-thesis “Stair-Climbing Autonomous Driving Device for Small Goods Transportation”, currently being written by Daniel Kattnig [16], with parts of the expected outcome being displayed in the following.

Logistics processes demand numerous requirements for autonomous application devices for parcel delivery, such as high reliability, weather-resistance, compliance with safety regulations, or the ability to navigate through angled stairwells. Heterogeneous construction of stairs in both, dimension and material add further to the challenges in designing such a device. However, it was found that a robot constructed based on the “Malteser-wheel”-technology [1, 10, 11] could fulfill the task, at least in an operational sense.

The process that could be deployed currently would see the operating personnel navigating the package delivery vehicle to the end customer. The device would match the packages with the location and take the right one(s) accordingly. Another intervention on part of the labor force is needed though, as the device is not able to unlock the main doors of the tenements. Environmental scans ensure that the package is delivered to the right flat, given they are marked with the address number.
In terms of efficiency, the device lacks compared to the current manual delivery as well as alternative, new technologies, such as drone delivery (see e.g. [17]), which is currently being tested e.g. by Amazon [18]. This is due to high expected costs for construction, slow operating speed, and the infeasibility of operating the system fully automated as long as autonomous vehicles are not being used broadly and no solution is found for unlocking doors with the robot. Further development in automation and associated construction (see also [17]) in the elementary transport units (transport-origitons) leads to further integration of this type of vehicle into transport logistics.

4.2 Industrial Transportation – Automated Guided Vehicles (AGV) – Industrial State of the Art
The automated guided vehicles (AGVs) were invented in America in the course of the 1950s and are now an important part of intralogistics. As the first application, a so-called tug, based on very simple tracking technology, was used to transport recurring group transports over a greater distance.

Intralogistics is the main field of application for AGVs. This means the control, implementation, organization, and optimization of internal material, as well as the goods, flow, information flows, and the handling of goods in industry, trade, and public institutions [19].

To this day, the AGVs are continuously developed and can be used in a variety of ways. The following criteria are decisive to be able to define which is the right design and technology for the respective application:

- Area of application and local conditions
- System complexity and number of vehicles required
- Navigation and control options
- Size and weight of the cargo to be transported

The functionality of navigation and the importance of safety play an important role in the selection of the right AGV and navigation technology. The interaction of the elements, which play a role in functionality and use, must be coordinated with the security systems so that the best suitable solution can be chosen. This solution must not cause any damage to the material, the environment, or the people surrounding the system. The navigation of the AGV depicts three very important areas. The first point is the current location of the AGV. The second point is the definition of the chosen target, which is directly related to the third point and that is to find the optimum way to the desired target. The navigation can either take place via a physical or virtual line or without any line. The respective manufacturer can decide which type of navigation to choose. Regarding security, the requirements must be strictly observed. Differences are depending on the system, but especially within Europe, relevant European standards and country-specific requirements have to be considered. The manufacturers should comply with these specifications, but the operators also have the responsibility to ensure correct use [19].

The key task of all AGVs is to transport a transport unit from a source to a target. This task is coordinated by the AGVS control system. An AGVS control system is defined by the VDI as follows: “An AGVS control system consists of hardware and software. The core is a computer program that runs on one or more computers. It serves to coordinate several driverless transport vehicles and / or takes over the integration of the AGV into the internal processes “ [20].

For the system architecture, it is fundamental that the control system also known as a fleet manager communicates with the respective AGV and then with the control system either based on a host or PLC interface. The automation mode is the main operating mode, which enables the AGVs to be used in 24/7 mode without interaction. Depending on the version of the respective vehicle, the charge cycles must be included in the calculation of the number of shuttles. However, the decisive criteria are:
“What should be transported? Where are the transfer points? What are the distances? How often should something be transported?” A general statement about the number is therefore not serious. All aspects must always be considered and analyzed. Learning in the course of the installation is also important here since one often encounters framework conditions that were not known in advance but have a direct influence on the system [19].

4.3 Thoughts About the Current Problems in the Industry Regarding Stairs and Floor Requirements
Generally, all suppliers have issues with uneven floors and stairs. This has got several reasons. First is that the shuttles are only allowed to have a small floor clearance due to safety reasons. If a shoe or something similar could get under the shuttle it may lead to injury. Second, the shuttles are constructed to be efficient in driving and have rather small wheels. If one of the wheels gets into a bigger gap it may get stuck. On the other hand, the shuttle usually carries some kind of load unit, which can have over 100kg depending on the supplier. If this load is being shaken and not secured enough it may fall and get damaged or worse, leading to an injury.

Stairs are mostly an issue because they can’t be detected by the shuttles. Safety systems are usually created to detect obstacles at a low height like legs from workers. This safety scanner can not check the floor for stairs usually.

5. Results, Discussions and Conclusions
The results of this work are an investigation about the systemic properties of machines with the special application to transport vehicles and their relation to generic development. First-principles are formulated, which can be further explored. The Malteserrollstuhl as a practical application was introduced. Future industrial applications were sketched, among others also especially in the field of AGVs, based on the Malteserrollstuhl patent applications.

In conclusion, there can be stated that there is still a big gap between the present patent applications and future industrial suitable applications. This gap can only be closed by further development of detailed mechanical constructions and prototyped-models that take into account the special needs of all stakeholders: Use in the logistical business application, solving the detailed transport tasks, solving the special need of the designed material that is to be transported, special needs of the customers who use or are delivered by means of the transport vehicles, the geographic environment, the sustainable lightweight construction, can be seen as only some of the future challenges for those kinds of applications.

Acknowledgment(s)
The authors wish to acknowledge the support of the Carinthia University of Applied Sciences for this work, namely Claudia Pacher, Franz Riemelmoser, Robert Hauser, and Erich Hartlieb. Part of the text was translated with the open DeepL Software.

References
[1] B. Heiden and T. Frohnwieser, "Treppensteigender Rollstuhl," (in German), Austria Patent 520885 Patent Appl. A 50107/2018, 15.02.2020, 2020. [Online]. Available: http://seeip.patentamt.at/Publication/PdfDocument/?DocumentId=b70adc49-43e5-41ad-b23d-544c95ccb678
[2] L. Wittgenstein, Philosophische Untersuchungen. Suhrkamp Verlag AG, 2019.
[3] J. C. Eccles, Evolution of the brain creation of the self. London etc.: Routledge, 1989, pp. XV, 282 S.
[4] G. Spencer-Brown, Laws of form Gesetze der Form, 2. Aufl. ed. Lübeck: Bohmeier, 1999, p. 202 S.
[5] B. Heiden, B. Tonino-Heiden, and M. Decleva, *Towards a Wittgensteinian Ladder for the Universal Virtual Classroom (UVC)* (Proceedings of SMART Living Forum 2019 - 14 November 2019, Villach, Austria). Villach: BoD, Norderstedt, Germany, 2020, pp. 71-77 https://forschung.fh-kaernten.at/aal/files/2020/05/11-heiden.pdf.

[6] B. Heiden *et al.*, "Orgiton Theory (unpublished work)," 2019.

[7] P. Läuchli, *Algorithmische Graphentheorie*. 1991.

[8] S. Dasgupta, C. Papadimitriou, and U. Vazirani, *Algorithms*. Boston: The McGraw-Hill Companies, 2008.

[9] B. Heiden and B. Tonino-Heiden, "Key to Artificial Intelligence (AI) (unpublished work, accepted for publication)," 2020.

[10] B. Heiden, "Malteserrollstuhl," Austria Patent Appl. AT Patent App. A1253-2012, 2012. [Online]. Available: http://seeip.patentamt.at/Publication/PdfDocument/?DocumentId=2ee1cd02-3b0f-4843-8eeb-84a54220067e

[11] T. S. Frohnwieser, "Konstruktion und Bau eines Funktionsmodells eines treppennäheren Rollstuhls auf Basis des Malteserradkonzepts," Bachelor Thesis, Carinthia University of Applied Sciences, 2016.

[12] V. Alieksieiev and O. Turchyn, "Studie der geometrischen Parameter der Handfahrwerke fürs Lade- und Abschlussarbeiten," in Thesen der Fünften Studierendenkonferenz zur Präsentation von Jahres- und Abschlussarbeiten, 2019, vol. 48: NTUU „KPI“, Kyjiv, pp. 5-7.

[13] G. Patents. *Treffensteigende Sackkarre* [Online]. Available: https://patents.google.com/patent/DE4409807A1/de

[14] U. o. Minnesota. *Stair Climbing Robot for Military and Security Applications*, Technology #z08062 [Online] Available: http://license.umn.edu/technologies/z08062_stair-climbing-robot-for-military-and-security-applications

[15] M. Eich, F. Grimminger, and F. Kirchner, "A Versatile Stair-Climbing Robot for Search and Rescue Applications," presented at the 2008 IEEE International Workshop on Safety, Security and Rescue Robotics, 2008. [Online]. Available: https://ieeexplore.ieee.org/document/4745874.

[16] D. Kattnig, "Stair-Climbing Autonomous Driving Device for Small Goods Transportation (ongoing work)," Masterthesis, Carinthia University of Applied Sciences, Villach, 2020.

[17] X. Mingxing, "Analyse möglicher Anwendungen von Gütertransportdrohnen (GTD), Entwicklung und Demonstration eines zugehörgen funktionellen Prototyps für ein automatisiertes Gütertransportgestell (GTG) und Modellierung und Simulation eines elementaren Gütertransportnetzes (GTN) von GTD im wirtschaftlichen Kontext," MSc Masterthesis, Carinthia University of Applied Sciences (CUAS), Villach, 2019.

[18] Amazon. (Info) Amazon startet Drohnen-Lieferung in Österreich! [Online] Available: https://www.preisjaeger.at/deals/info-amazon-startet-drohnen-lieferung-in-osterreich-202986

[19] T. A. G. Ullrich, *Fahrerlose Transportsysteme*, Wiesbaden. Springer Fachmedien Wiesbaden GmbH, 2019.

[20] VDI 4451-7 "Kompatibilität von Fahrerlosen Transportsystem (FTS) - Leitsteuerung für FTS". Berlin: Beuth-Verlag, 2015.