Narrative designed proposals of mechanical or electro-mechanical optimization to the current wheelchairs used by people with severe locomotion restraints

DOI: 10.35530/IT.071.04.1830

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ABSTRACT – REZUMAT

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The field of mechatronic/robotic wearable exoskeletons, specifically those designated for assistance/rehabilitation in severe neuro-/locomotor disabling conditions in the lower limbs, is considered to have a great potential for radically changing the harsh condition of wheelchairs users, by restoring their defining human traits: bipedal, vertical, stance and gait. But even the most advanced such complex devices, are not yet effectively able to largely replace the wheelchairs. Therefore, until the overall complete wheelchairs' substitutes, will meet, in this purpose, all the necessary related requirements, we have determined, and accordingly, designed – from a double perspective: of professionals and of (a) consumer – a series of necessary and rather accessible/feasible, consistent: mechanical and electro-mechanical improvements, to the current common type of wheelchairs, in order to improve the global functioning, autonomy and consequently, the quality of life in the needing people, with severe mobility restraints. These, for now, narratively innovative concepts and specifically designed, practical/technological-constructive solutions, target 10 main kinds of beneficial outcomes, i.e. a decalogue and their derivatives to be expected (most of them previously imagined by us but not completely designed until now, two of them already achieved but which need updating and other four entirely new), that could result in an "all-in-one" product paradigm which, to our knowledge, is not available at present. This model of wheelchair we propose is, at the same time, modular, so a certain consumer can purchase/ be offered only his/her own case-specific needed optimization components of it.

Keywords: *severe mobility restraints, improved wheelchair, variable geometry, multi-functional rear wheel guards, pliability, modular all-in-one product paradigm*

Propuneri și proiectare – narative – pentru optimizare mecanică sau electro-mecanică a fotoliilor rulante actuale, folosite de persoane cu restricții severe de locomoție

Domeniul exoscheletelor mecatronice/robotice purtabile, în special al celor proiectate pentru asistare/recuperare în suferințe neuro-locomotorii sever dizabilitante la membrele inferioare, este considerat a avea un potențial de schimbare radicală a condiției utilizatorilor de fotolii rulante, prin restabilirea trăsăturilor umane definitorii: poziția bipedă, postura și mersul verticale. Dar, chiar și cele mai avansate astfel de dispozitive complexe, nu sunt încă efectiv capabile să înlocuiască pe scară largă fotoliile rulante. De aceea, până când substituenți deplini ai fotoliilor rulante vor întruni, în acest scop, toate cerințele necesare conexe, noi am stabilit și, consecutiv, proiectat – dintr-o dublă perspectivă: a profesioniștilor și a consumatorului – o serie de optimizări mecanice sau/și electro-mecanice, consistente, necesare și relativ accesibile/fezabile, pentru fotoliile rulante actuale, cu scopul de a îmbunătăți funcționalitatea globală, autonomia și în consecință, calitatea vieții persoanelor cu restricții severe de locomoție. Aceste – deocamdată narative – concepte inovatoare și soluții practice, tehnologic-constructive special concepute, vizează 10 tipuri principale de rezultate benefice, respectiv, un decalog și derivate ale acestuia (cele mai multe dintre ele imaginate de noi anterior, dar fără a fi fost complet proiectate până acum, două dintre ele deja realizate, dar care necesită actualizări, și alte patru complet noi), din care ar putea rezulta un produs în paradigmă "toate în-unul", care, după cunoștința noastră, nu este disponibil în prezent. Acest model de fotoliu rulant pe care îl propunem este, în același timp, modular, astfel încât un utilizator poate să achiziționeze/să-i fie oferite doar componentele de optimizare specifice nevoilor proprii ale cazului respectiv.

Cuvinte-cheie*: restricții severe de locomoție, fotoliu rulant îmbunătățit/optimizat, geometrie variabilă, apărătoare roți spate multi-funcționale, paradigma produsului modular "toate în-unul"*

INTRODUCTION. BACKGROUND

As detailed elsewhere [1], including the personal experience of one of this article's main author – both an academic physician of Physical and Rehabilitation Medicine (with special focus on NeuroRehabilitation) and respectively, of Gerontology and Geriatrics, but also a chronic, physically incapacitated person, wheelchair user – the impossibility to perform two connected fundamental, defining features of the human physiology, i.e. bipedal: (ortho)static posture and gait, represents the severest disability and handicap [2] that affects – as systematized in the World Health Organization (WHO)'s (newer) paradigm regarding human functioning – all the levels within this describing framework, namely "Body functions and structures", "Activities and Participation", resulting in "Impairments… problems in body function or structure such as significant deviation or loss" –, "Activity limitations… difficulties an individual may have in executing activities" – and "Participation restrictions… problems an individual may experience in the involvement in life situations" [3]. This seriously lowers, at the same time, the quality of life in people with such kind of – no matter the cause – marked invalidity.

Consequently, the cartoon "of a person in the wheelchair is the worldwide used symbol for handicap" [4].

On the other hand, there is evidence for persons who cannot achieve/keep vertical, bipedal, stance and/or gait – at least for post spinal cord injury (SCI) paraplegics who have wheelchairs manually propelled "as their primary means of mobility" [5] – that "their ability to perform manual wheelchair skills is associated with higher community participation and life satisfaction. Factors contributing to low success rates need to be investigated and interventions to improve these rates are needed" [5].

It should also be noted that a task/skill with the lowest success rate – included among the items of the Wheelchair Skills Test Questionnaire (WST-Q), too [6] – is the rise/flight "ascending (19.6%) ... 15-cm curb" [5].

In older people there is an augmented necessity to avail "mobility support" [7] wheeled mobility equipment (WME). "From 1990–2005, WME use grew 5% per year, while mobility difficulty declined among the elderly and remained steady among working-age persons. This contrast suggests a reduction in the unmet need for WME" [8]. For instance, in individuals aged ≥ 50 years, the need for wheelchairs in order to overcome mobility – especially of ambulation kind – difficulties/reduction and hence, participation restrictions [9], becomes higher than in adolescents and younger adults; specifically: ≥ 85year old wheelchair users are over than 20 times more numerous than those between 12–44 years of age [9]. Additionally, we have to mention the practically global, alert rhythm of demographic ageing [10–12] prone to already generate – and in the future, more and more – elderly, including with mobility problems, thus also an enhanced number of wheelchairs users. As ageing consists of progressive, overall, functional decline – even possibly of frailty [13], especially in the "oldest-old" [14] – obviously their skills/capabilities regarding the use of wheelchairs become lessened; so, this is a supplementary but consistent rationale for aiming at the manufacture of better wheelchairs, which could provide enhanced compensatory assistance as the consumer's general endurance and dedicated abilities – as mentioned above – fade.

Despite important progresses made, especially in less than a (last) decade, in the field of mechatronic wearable exoskeletons – for bionic bipedal standing and walking, too – the eagerly awaited completely available, from all essential points of view: perfectly safe, "effectively wearable" (easy to be attached to and put in service – obviously, preferable – by the user, and concerning the respective man-machine interaction, as well), enough energy storage/provision, "appropriateness for long time use" – including "in community" –, acceptable aspect when equipping/observed together with the consumer, truly affordable/cost-effective [4] such a kind of very complex, fully functional device, is still to come.

Considering, on the one hand, the assertion: "… unfortunately, data on the prevalence of SCI are sparse. Currently there are no reliable global or regional estimates of all-cause SCI prevalence" and on the other, a very approximate prevalence average worldwide, based on the estimation data from 6 countries, for traumatic and 2 countries for non-traumatic SCI – both in [15] – we have calculated, largely, that currently, at an actual world population of around 7.6 billion people [16], there could be about 11.000.000 post SCI survivors, and as over 90% of (only) post traumatic SCI are wheelchair users [17], and if we added other categories of related consumers, within a global approximation, such persons in need would be, more or less, 1% of a population [18]. This also entails the obvious health-assistive and socio-economic importance (regarding the support to the clients for participation within the family and the extended environment – even for employment, if medically possible – but also the market for these extremely important mobility aids/assistive devices) of the subject matter we approach. Thereby, the wheelchair is considered to be "one of the most commonly used assistive devices for enhancing personal mobility, which is a precondition for enjoying human rights and living in dignity and assists people with disabilities to become more productive members of their communities… step towards inclusion and participation in society" [18].

"In 2012, it was estimated that worldwide over 185 million people use a wheelchair daily, and almost 20 percent of the world's population is now aged over 65 years, and that is forecast to exceed 35 percent by 2050" [19]. So, it is important to develop advanced devices for assisting the post SCI patients or other categories of inpatients that need such a device for achieving some degree of autonomy and thus being more active and increasing their QoL.

Based, including on the older but valuable document [18] (our narratively innovative proposals for technical/functional-assistive optimizations to the actual wheelchairs considered knowledge from it, too, including for their modular construct – see further), the WHO, coagulating and leading a large panel of stakeholders worldwide, has initiated in 2013 and launched in 2014, a comprehensive international project – through a paradigm shift: the "Assistive Health Technology" and "Assistive Health Products" concepts, split from the more general design of "assistive products and technology" [20]. A dedicated – and pragmatic – task/effect aimed and supported, including by this initiative endorsed by the WHO, is the achievement of the WHO Priority Assistive Products List (APL) – which raises "awareness among the public, mobilizes resources and stimulates competition" and "provides guidance for procurement and reimbursement policies, including insurance coverage" [16, 21]: among 100 of such devices, wheelchairs hold seven places (between the first 7–13 positions), i.e. – aside lower limb orthoses – the largest framing [22].

Under these circumstances, as the individuals who cannot stand and/or walk, mandatorily need mobility in their everyday life, until it will be truly possible for wheelchairs to be replaced by the above-mentioned robotic wearable type of advanced orthoses, the former might benefit of some – basically mechanical/electro-mechanical, hopefully not expensive, but we consider, very useful – improvements, which we shall describe in this article.

In the specific literature, there is a series of guidelines (one of them approved by the WHO's Guidelines Review Committee on 16 April [18] that refer to an adequate manual wheelchair. In order to be functional and appropriate for the user, the wheelchair should enable outdoor advancing and it should "provide proper fit and postural support; is safe and durable; is available in the country and can be obtained and maintained and service sustained in the country at an affordable cost" [23].

The above-mentioned guidelines are important for conceiving such devices as regards design, fabric and provision [18].

Disability, being actually an important and difficult multidisciplinary problem including at the social level, it is recommended for any country to have a national strategy regarding wheelchair standards as a basis and further, to merge such an endeavor with the local capabilities of architectural, conveyance and medical kinds for ensuring, thus, effective inclusion and consequent acceptable quality of life for the respective consumers [18].

We also consider the five major goals of prescribing a wheelchair for people with severe neuro/locomotor disabilities, as already mentioned in the literature [24]: "to maximize the client's independent mobility; prevent/minimize deformity or injury; maximize independent functioning; project a healthy, vital, attractive 'body image'; and minimize short- and long-term costs" [25].

It must be specified that we first started to conceive such optimizations more than ten years ago. We have then implemented them partially by means of certain technical additions to a standard wheelchair, and reported [26], together with mentioning the supplementary improvements we intended, at that time, to design.

METHOD AND ITS RATIONALE

Considering these ideas of ours, for optimization (and other newer – including enlarging, more recently, our panel of specialists/co-authors – being at present, still in the design stage) we reckon it would be beneficial to make them known, as they haven't yet been published, even as narrative technical proposals. Thus (at least some of them) might eventually reach a long delayed – but we still strongly, constructively and fairly consider them useful – translational course, for the benefit of so many wheelchair users.

The following narrative optimization proposal that will be presented below, result of a Delphi kind method – professionals in the medical and engineering/technical fields – with important consisting in the fact that one of the main authors is not only a professional in the field but also a chronic complete paraplegic, and therefore, a permanent wheelchair user.

Accordingly, the target population that may benefit from the improved mechanical/electro-mechanical facilities in the current wheelchairs, we propose, has severe ambulation restrictions caused, in principal, by neurologic conditions: thoracic, lumbar/-sacral and/or lower (C7 and downwards – thus mostly paraplegics) cervical, post SCI – traumatic and/or non-traumatic – conditions, poly-neuropathies in the lower limbs, dangerous (as falling risk) balance disorders, but also by muscle-skeletal ones (thigh bilateral amputations and/or multiple invalidating lesions in appendicular bearing joints – with poor/no availability, for different reasons, for endo-prosthetic/s approach), and/or by cardio-/respiratory failure, respectively by severe morbid obesity; this entails adequate bilateral force and dexterity in the upper limbs, including with an acceptable/functional capability to handle transmission of driving voluntary commands, to the mechanical and/or electro-mechanical effecter structures of the wheelchair.

Further, in the elapsed above-mentioned period, improvements concordant with those we have conceived, have been fulfilled regarding making lighter wheelchairs within other researches and consequently, newer models of wheelchairs, already in use [27–28].

In a recent literature review about step-climbing power wheelchairs [29], it is mentioned that some of the current wheelchairs that can climb on steps are still in research, so "these devices represent a variety of approaches to the tasks of climbing a single step or continuous stairs, including leg-wheel hybrid systems, spider wheels, additional structures for lifting, and crawler tractors".

Although the prototype tests that were found in this research were made in some appropriate and controlled conditions, the results were not comparable between articles and two of these reports [30–31] which were analyzed in the above-mentioned article had important clinical studies but their results weren't very convincing and couldn't be used for a comparative evaluation of the efficacy of the devices by other researchers.

The conclusion is that, with only one such device existing on the market, what is needed first of all is "to develop a well-specified driving evaluation" which can mention the most common inconveniences encountered by wheelchair users and also to increase the accessibility of these devices on different kinds of land with bumps, to "make their mechanisms and sensors reliable" and to produce a device at a good price and high quality [29].

RESULTS

In order to achieve the improvement goals within an afore-mentioned all-in-one product paradigm of a narratively innovative upgraded model of wheelchairs, we herein describe further, in tabular form, exemplified by suggestive figures, our related decalogue and their derivatives of optimization proposals. Specifically, in a preliminary brief enumerative synthesis these are (in an all-in-one integrative design):

- propelled by his/her own upper limbs and electrically – with optimization of the batteries' positioning – powered by motors placed on the big wheels;
- (novelty item) improved way of manual – or electromechanically initiated – propelling (through and over each big wheel – but without contacting it – tilting guard, thus resulting, on the one hand, in the possibility to spare push rings and of narrowing, at the same time, the overall width of the wheelchair and on the other hand, to avoid the hands accidentally touching the wheels – which can be dirty);
- (novelty item) better ground bumps/kerbs negotiation (through an installed facility for about 30 degrees elevation of the front/small wheels – enabling to climb/stride on unevenness of the ground of maximum 20 cm;
- (correlated) with another one for instant anti-overturning when back tilting;
- (novelty item) an additional braking capability that would operate only when the manual or electrical power to ascend the wheelchair is insufficient compared to the gravitational force of a too sharp ground profile;
- adjustable fittings to stabilize the user's (paralyzed) feet within the footrest(s) – in order to avoid their displacement due to shattering actions caused by advancing on ground asperities;
- damper elements added;
- assisted verticalization – but at the same time, with pliability/ foldability keeping – at variable angles (up to almost 90 degrees – done and controlled/modulated mechanically, or better, electrically – constructive capability including proneness to prophylaxis of pressure sores in the buttocks region: an important issue encountered in the wheelchair, long-term, daily use);
- (novelty item) easy/prompt manual adjusting of the wheelchair's backrest verticality with +/– 30–40 degrees (depending on the necessity to maintain the client's center of gravity when descending or respectively, climbing more abrupt slopes);
- possibility to access and/or turn in tight spaces – like some elevators/lifts, corridors – including through antero-posterior variable geometry (antero-posterior slide of the support for the feet, connected with their possibility to be moved in both frontal and sagittal (not only backward but also front lifted) plans.

All these improvements proposed are intended, in sum, to avoid significantly enhancing its total weight (about 15 kg), so that our multimodal all-in-one model of wheelchair can remain available (with its pliability/foldability kept) for transportation in a car trunk, too.

Regarding pliability/foldability – invented over 80 years ago [32] – and which is a basic capability, from the essential point of view of a daily comfortable wheelchair's handling: aside a functional related specific mechanical constructive solution (most frequent of a X-shaped/"folding cross-brace frame" [33] design, type), a sine qua non underlying contributive component is the avail of a textile material, mandatory to be used in both, the bottom/ hammock and the backrest, usually with "sling upholstery" [33] – especially in order to avoid pressure sores and to make a better and more protected/fitted position of the customer in the device – that may consist of "foam and combinations of foam/gel or foam/air" [34] of such kind of a wheelchair. This must have, in a balanced manner, enough hardness – "nonsag materials" [35] – and flexibility, and at the same time, it needs to be lasting/resilient, non-toxic, non-allergenic, waterproof, flame retardant and easy to be cleaned. Commonly used synthetic fabrics, in this purpose, are polyvinyl chloride (PVC), polyester, nylon.

It should be mentioned that our about 15 kg weight wheelchair will have all the upgrades stated above, including detachable leg rest – although, similar wheelchairs, without any improvements, found in the marketplace weight also 15–27.21 kg (33–60 lbs) [36–37]. Carbon fiber wheelchairs with no detachable footrest could weight, indeed, less than 10 kg but our improvement proposal does not fit to this design.

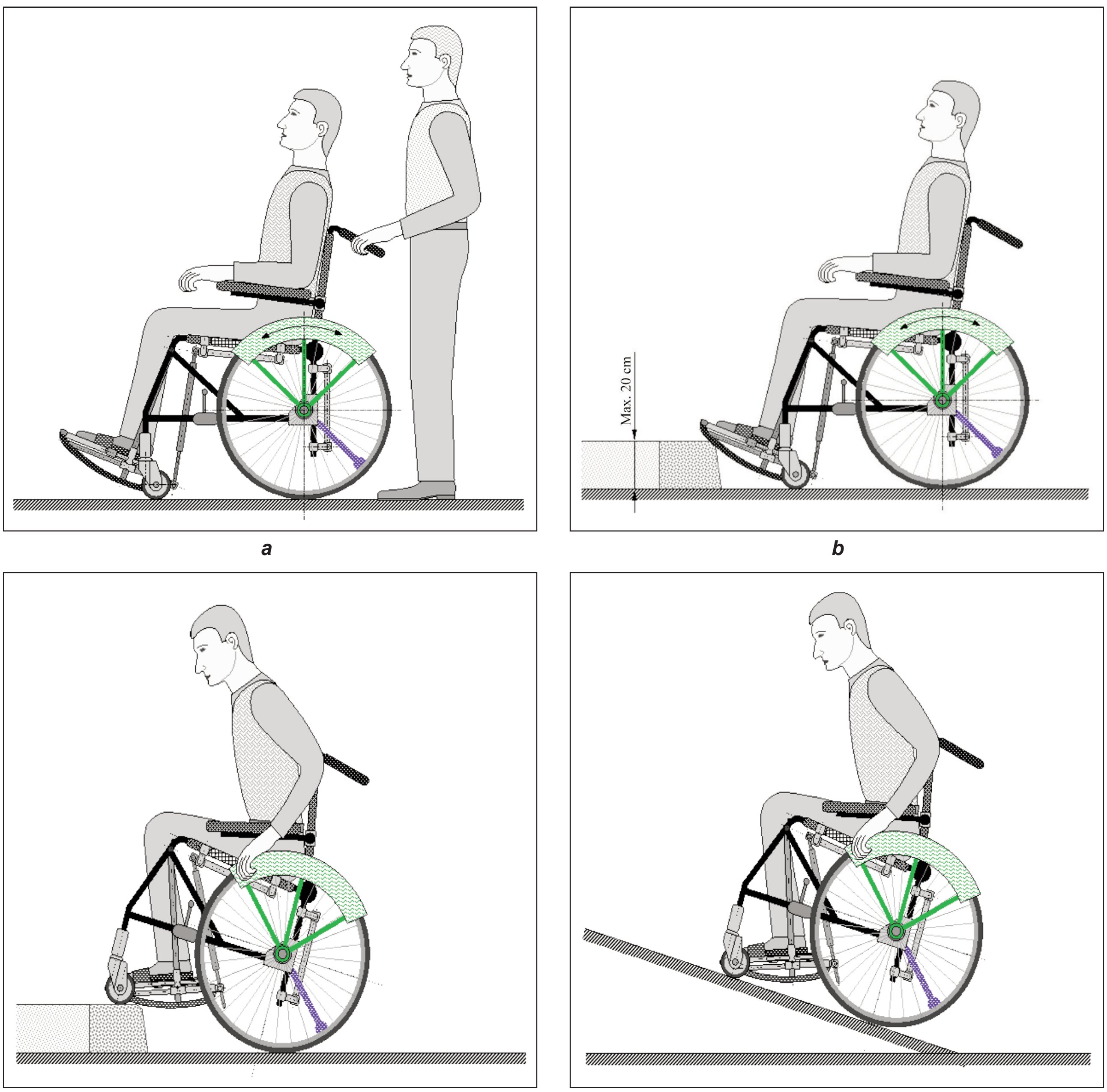
Although some of these advancements are already being applied in the motorized wheelchair constructions, we will use them together with our original concepts for the narratively intended optimization of wheelchairs.

SYSTEMATIZATION OF THE MULTIFUNCTIONAL MODULAR ALL-IN-ONE TYPE OF WHEELCHAIR OPTIMIZATIONS

To the constructive variants of the wheelchair mentioned in table 1, a number of original optimization solutions (some of them patent pending) will be applied, according to the main 10 beneficial outcomes mentioned above, solutions which target constructive and functional upgrading of the wheelchairs, and increasing the autonomy degree of their users (tables 2 and 3).

Table 1

CONSTRUCTIVE VARIANTS OF WHEELCHAIRS, SUBJECT TO OUR IMPROVEMENT PROPOSALS	
A	**wheelchair** with foldable bearing structure and manual actuation: the basic modular variant A (figures 1, 2 and 3)
B	**wheelchair** with foldable bearing structure and electric actuation: the structure is based on variant A, to which the specific modules are added (figures 3 and 4)
C	**wheelchair** with bearing structure allowing for verticalization, with mechanical actuation: basic modular variant C includes also modules of variant A (figures 5 and 6)
D	**wheelchair** with the bearing structure allowing for verticalization, with electric actuation: the structure is based on variant C and includes the specific modules of variant B (figures 6 and 7)



a *b* *c* *d*

Fig. 1. Situations encountered when using a/ the wheelchair: *a* – patient sitting in the wheelchair; *b* – patient in the wheelchair next to a sidewalk; *c* – climbing the sidewalk; *d* – climbing a slop

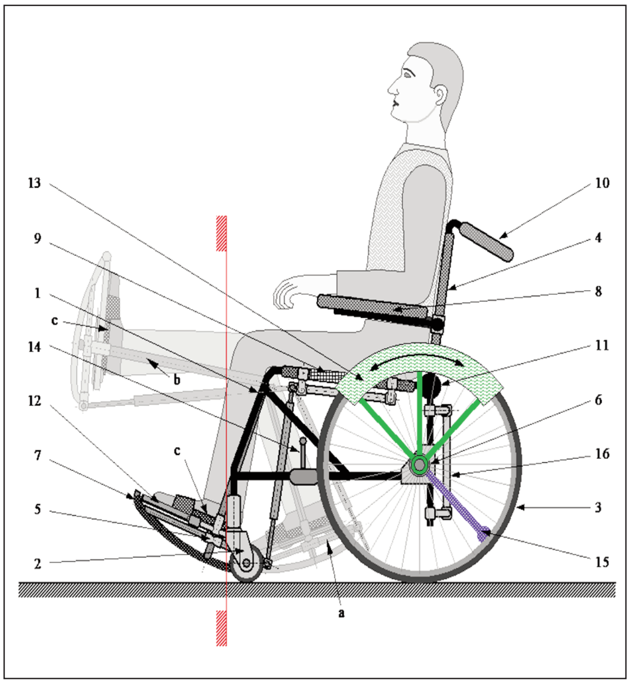


Fig. 2. Component of the manually driven wheelchair: *1* – basic folding frame; *2* – swivel front wheel; *3* – rear wheel; *4* – seat with adjustable backrest; *5* – adjustable feet support; *6* – anti-overturning device; *7* – bumper climbing device; *8* – folding adjustable armrests; *9* – command block; *10* – assist/propelling handles from the attendant; *11* – backrest-angle tilting device; *12* – adjustable feet stabilization system; *13* – multifunctional: protective and propelling guard; *14* – mechanical brake with manual actuation enabling counteract gravitational backward movement; *15* – auxiliary/optional anti-overturning facility; *16* – folding/de-folding mechanism of the wheelchair; a – the fully retracted position of the adjustable feet support; *b* – constructive facility that enables for intermittently posturing the user's feet in cvasi horizontal position – prone to an improved anti-gravitational circulation, of venous-lymphatic drainage in the lower limbs; *c* – velcro standard support for the heel region

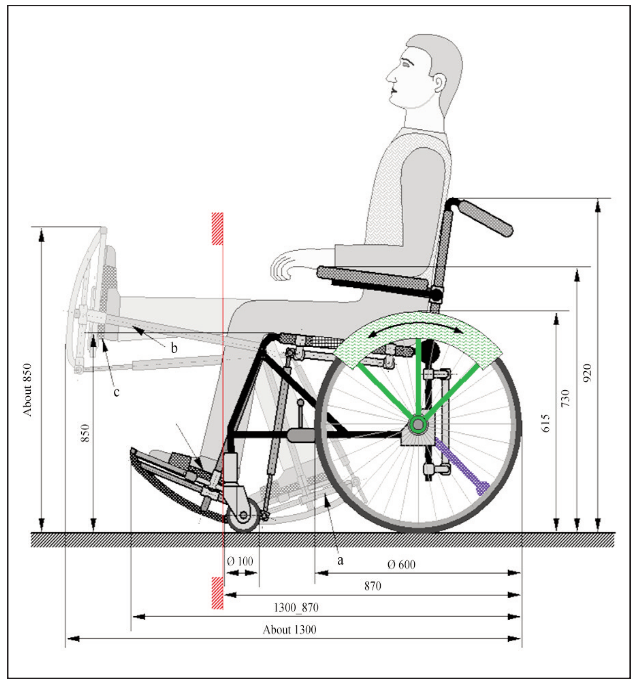


Fig. 3. Overall dimensions of the wheelchair – variants A and B (dimensions in mm): a – The fully retracted position of the adjustable feet support; b – Constructive facility that enables for intermittently posturing the user's feet in cvasi horizontal position – prone to an improved anti-gravitational circulation, of venous-lymphatic drainage in the lower limbs; c – Velcro standard support for the heel region

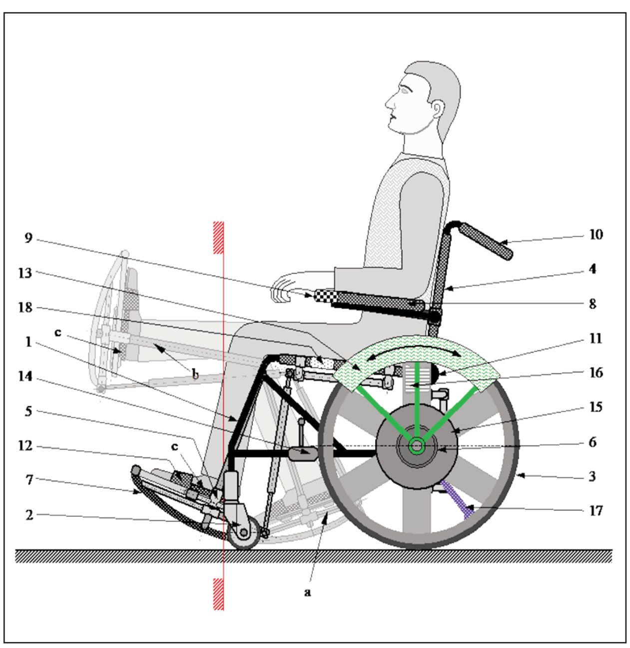


Fig. 4. Component of the electrically driven wheelchair: *1* – basic folding frame; *2* – swivel front wheel; *3* – motorized rear wheel; *4* – seat with adjustable backrest; *5* – adjustable feet support; *6* – anti-overturning device; *7* – bumper climbing device; *8* – folding adjustable armrests; *9* – electrical control block; *10* – assist/propelling handles from the attendant; *11* – backrerst-angle tilting device; *12* – adjustable feet stabilization system; *13* – multifunctional: protective and propelling guard; *14* – mechanical brake with manual actuation enabling to counteract gravitational backward movement; *15* – rotary actuator; *16* – accumulator battery; *17* – auxiliary/optional anti-overturning facility; *18* – command facility for adjusting the backrest-angle tilting device; *a* – the fully retracted position of the adjustable feet support; *b* – constructive facility that enables for intermittently posturing the user's feet in cvasi horizontal position – prone to an improved anti-gravitational circulation, of venous-lymphatic drainage in the lower limbs; *c* – velcro standard support for the heel region

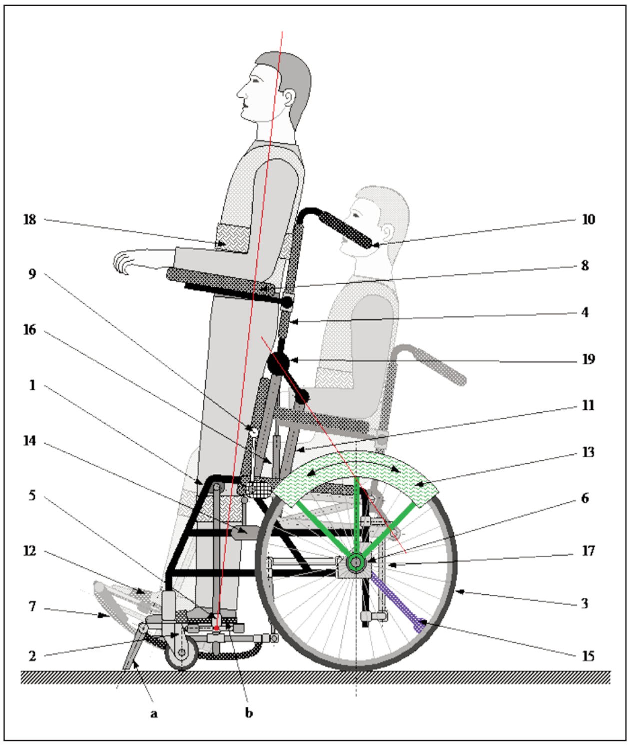


Fig. 5. Component of the wheelchair with manual actuation that allows verticalization: *1* – basic folding frame; *2* – swivel front wheel; *3* – rear wheel; *4* – seat with adjustable backrest; *5* – adjustable foot support; *6* – anti-fall autoblocker device; 7 – bumper climbing device; *8* – folding adjustable armrests; *9* – seat actuation lever; *10* – assisting handles by attendant; *11* – seat-upright mechanism; *12* – feet support and stabilization system; *13* – protective device; *14* – mechanical brake with manual actuation; *15* – auxiliary/optional facility anti-fall; *16* – user weight compensation device; *17* – folding/defolding mechanism of the wheelchair; *18* – support belts (thorax and knee) of the user; *a* – folding stand for securing the vertical position of the user; *b* – velcro standard support for the heel region

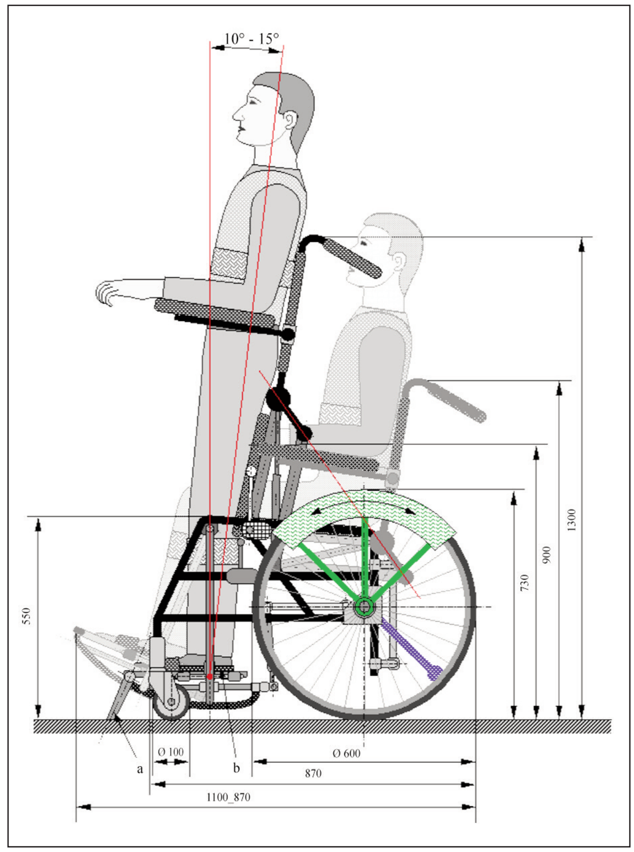


Fig. 6. Overall dimensions of the wheelchair – variants C and D (dimensions in mm): *a* – folding stand for securing the vertical position of the user; *b* – velcro standard support for the heel region

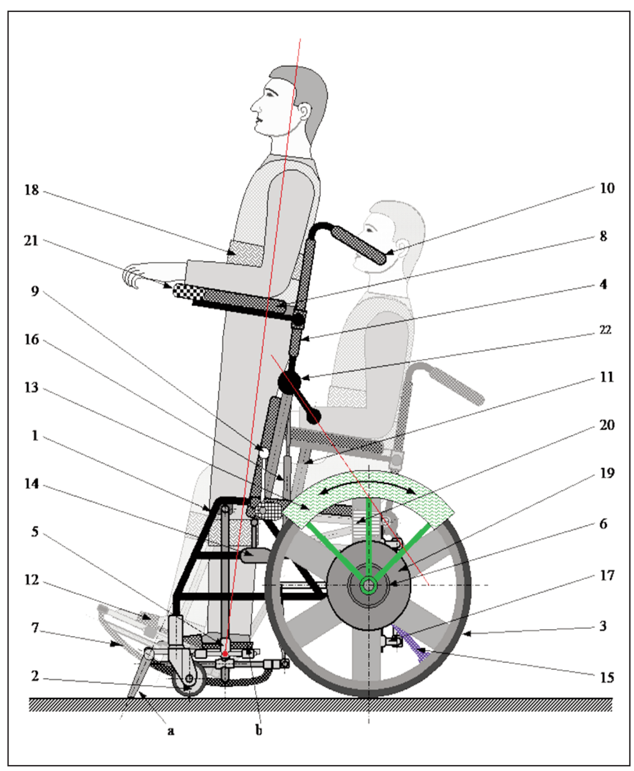


Fig. 7. Component of the wheelchair with electric actuation that allows verticalization: *1* – basic folding frame; *2* – swivel front wheel; *3* – motorized rear wheel; *4* – seat with adjustable backrest; *5* – adjustable feet support; *6* – anti-overturning device; *7* – bumper climbing device; *8* – folding adjustable armrests; *9* – seat verticalization lever; *10* – assist/propelling handles from the attendant; *11* – seat verticalization mechanism; *12* – adjustable feet stabilization system; *13* – multifunctional: protective and propelling guard; *14* – mechanical brake with manual actuation enabling to counteract gravitational backward movement; *15* – auxiliary/optional anti-overturning facility; *16* – user's weight compensation device; *17* – folding/de-folding mechanism of the wheelchair; *18* – support belts for user's thorax and knees; *19* – rotary actuator; *20* – accumulator battery; *21* – electrical control block; *22* – backrerst-angle tilting device; *a* – folding stand for securing the vertical position of the user; *b* – velcro standard support for the heel region

Table 2

ORIGINAL CONTRIBUTIONS FOR OPTIMIZING WHEELCHAIRS IN ORDER TO INCREASE THE AUTONOMY DEGREE OF THE USERS					
No.	**Description of the proposed optimizations and facilities**	**Variant***			
		A	**B**	**C**	**D**
1	2	3	4	5	6
1	**The lightweight bearing structures with about** 15 (kg) weight** Aluminum alloy pipes and carbon fiber composite materials will be used both, for the bearing structure and for the motor wheels, **with integrated actuators and accumulators**	≥12 kg	≥14 kg	≥13 kg	≥15 kg
2	**The modular foldable bearing structure** (see specifications in table 3) Bearing structures of variants, **A**, **B**, **C** and **D** are composed of the following mechanically interconnected common modules: • Basic frame, foldable and adjustable • Swivel front wheels • Rear wheels • **Multifunctional wheel guards on the upper 1/4 of rear wheels** • Seat/Stand support platform **with adjustable backrest** • Adjustable **feet** (not only heels – as currently in the standard wheelchairs) **support with stabilization facility consisting of an extended hook-and-loop** (**Velcro**) **straps/loops system** • **Anti-overturning facilities** • **Bumper compensation device** • Folding adjustable armrests • **Damper elements** • Constructive facility that enables for intermittently posturing the user's feet in cvasi horizontal position – prone to an improved anti-gravitational circulation, of venous-lymphatic drainage in the lower limbs, coupled, within a same swivel kind of system, with the facility of sliding backwards of feet support (see below) • Assist/propel handles from the attendant bearing structures of variants, **A**, **B**, **C** and **D** are **foldable, so the wheelchair can be put in the trunk of a car**	A	B	C	D
3	**Adjustment of the backrest position to various specific situations of use: +/– 30...40 degrees** Equipment of the wheelchair backrest with subassemblies and options to allow the suitability of its position to specific situations shown in use, by its tilting variation, performed quickly and easily by the user	A	B	-	-
4	**Sliding possibility in the sagittal plan of the feet support** The feet support will be provided with sliding possibility in the sagittal plan for the legs up to the user's knees, in the same plan, in order to allow access into elevators or other narrow antero-posterior spaces	A	B	-	-
5	**The bearing structure allowing the lifting of the assisted person** In order to facilitate the pro-gravitational urinary flow and stools, as well as to allow the beneficiary touching of some objects at a superior height than conferred by the wheelchair (shelves, bookcases/cabinets); **verticalization capability does not exclude foldability**	-	-	C	D
6	**Anti-overturning facilities of the rear tilt trend/risk of a wheelchair** Ensures the rear wheels' blockage in relation to the bearing structure, when the weight assigned to the front wheels decreases under a certain amount (consequent to the acceleration necessary to be induced to the wheelchair), for "overlapping" bumps, as well as the referral, at the hub level of each rear wheel, of the appearance of an angular acceleration over a safety preset limit (on the principle of automatic mechanical locking of the car seatbelt)	A	B	C	D
7	**Multifunctional wheels guards on upper 1/4 of the rear wheels** To protect the user's hands from soiling during self-propelling also for manual direct actuation at the wheel's hub level, while achieving through eliminating the external maneuvering circles, to reduce the lateral gauge of the wheelchair, prone to facilitate access to narrow spaces	A	B	C	D
8	**Brakes** Two constructive solutions are foreseen: on the one hand, equipping the wheelchair with a hand-operated mechanical system for each rear wheel (with the succession: unbraked, braked both ways, braked on running back) and on	A	B	C	D

Table 2 (*continuation*)

1	2	3	4	5	6
	the other hand, for electrically powered wheelchairs – with a system that allows simultaneous transmission, on both rear wheels, of all braking commands, given with one hand, from a single command center, the location of the brake command being placed in the seat support structure area under the user's thighs, in a convenient position for handling. Additional braking capability that would be operated only when the manual or electrical power to ascend the wheelchair is insufficient compared to the gravitational force of a too sharp ground profile; propelling again the wheels guards, the user will be thus able to continue climbing with his/her wheelchair the respective slope (if its sharpness does not exceed the above mentioned anti-gravity – manual or electrical – force)				
9	**Folding adjustable armrests** Folding/tilting armrests are provided, with adjustable angles and lengths by telescoping, indexable, elements that will also serve to operate other optional devices of the wheelchair (adjustable tilting backrest device)	A	B	C	D
10	**Pockets for operating with fingers all the electrical commands** Provision of areas in spaces at the lateral edges of the seating support structure, anterior front of the rear wheels, for operating with fingers of some levers or command buttons	-	B	-	D
11	**High efficiency motors and accumulators mounted in the rear wheels' structure** Rotative actuators with a high yield and the accumulator's battery mounted in the rear wheels' structure must ensure a functioning autonomy of minimum 3 hours	-	B	-	D
12	**Possibility for the wheelchair to climb on sidewalk curbs of maximum 20 cm by self-propelling** The feet support is equipped with the possibility to run over an obstacle with the height of maximum 20 cm, by self-propelling (figures 1, 2, 4, 5 and 7)	A	B	-	-
13	**Endowment with damping elements that take on shocks when moving** Isolation of the user from the shocks that occur when the wheelchair moves is done either by mounting dampers for each wheel and/or by insulating the seat structure of the basic pliable frame	-	B	C	D
14	**Adjustable <u>feet</u>** (not only heels – as currently in the standard wheelchairs) **support with stabilization facility consisting of of an extended hook-and-loop** (**Velcro**) **straps/ loops system**	A	B	C	D

* The significance of the variants is presented in table 1.
** Information values without the weight of the optional electro-mechanical components.

Table 3

ADDITIONAL CONSTRUCTIVE SPECIFICATIONS OF THE WHEELCHAIR'S MODULAR STRUCTURE, REGARDING SUGGESTED OPTIMIZATIONS AND RELATED FACILITIES	
No.	**Additional constructive specifications of suggested optimizations and related facilities**
1	2
1	**Basic pliable frame** Frame folding capacity is based on a precise rectilinear guiding mechanism, characterized by the existence of only rotating couplings, that gives the mechanical structure a much larger spatial rigidity, a much smaller folding/ unfolding effort of the users and the possibility for a simpler maintenance To compensate for uneven grounds, the folding frame will be provided, in certain joints, with elastic insertion, constructive solution that will reduce the rigidity of the folding frame in order to diminish its mechanical stress and mitigate the shocks incurred by the user
2	**Swivel front wheels** They are each provided with a system for detracting the tendency of loss of contact with the ground, by automatically tracking the force with which the respective swivel wheel is loaded When both front wheels contact the ground with forces under a certain prescribed value, the protection system against the wheelchair roll-over/over-turning is triggered. This system consists of two anti-overturning telescopic rods, located on each side of the rear wheels and/or by blocking the rear wheel hubs automatically (on the principle of the automatic mechanical locking of the car seatbelt) when a predefined value of rotation acceleration is exceeded

Table 3 (*continuation*)

1	2
3	**Bumper climbing device** The adjustable feet support will be provided with the possibility of rotation in the sagittal plan relative to the user's knees position, with circular rod (on its inferior edge located in the extreme lateral inferior side of the adjustable supports), in order to climb over bumps of maximum 20 cm; The circular rolling range of the adjustable supports is situated at a height from the ground which is smaller than the wheelchair's pivotal wheel rotating radius (figures 1, 2, 4, 5 and 7)
4	**Assist handles** For the protection of both the wheelchair user and the attendant, assist handles are provided with the possibility to control braking when descending on inclined surfaces; this also prevents going back while climbing slopes

CONCLUSIONS

The existence of optional modules, some of them common for all constructive variants of wheelchairs and compatible with them, allows the user to optimize gradually, in time, his/her own wheelchair, depending on additional requirements and financial possibilities. For the producers of the four variants of wheelchairs, manufacturing costs would be lower due to the endowment of the constructive variants with modules, common manufacturing materials, and technologies.

We consider that this proposed system of wheelchairs – having a modular structure with many elements common to all the four variants – allows a specific user to purchase only the components necessary for a specific optimization in his/her wheelchair; thus, the price of any variant cannot exceed, significantly, the price of similar contemporary wheelchairs, although it offers, in one product, many additional functions given by the additional optimizations and facilities proposed.

Considering these ideas of ours, at optimization – and other newer ones which are, at present, still in the design stage (prone to be patented) – we reckon it would be beneficial to make them known, even as narratively technical proposals.

Although they might be too numerous, the technical solutions for optimization we have proposed are, in our opinion, beneficial and their – hopefully soon – materialization would probably contribute to an overall better functioning and living for the wheelchair users.

AUTHOR CONTRIBUTIONS

All authors listed have equally contributed to this work and approved it for publication.

ACKNOWLEDGMENTS

We herein mention (chronologically) the names of all the partners who, along time, have viewed the original ideas we have conceived for optimizing the mechanical or electro-mechanical assistive performances of current wheelchairs, and thank them for their related consideration: Catalin Orasanu, Stefan Tudorel Craciunoiu, Cristian Grozea, Florin Popescu, Loredana Paun, Raluca Nita, Steffi Keller, Hannah Wolff, Ivo Haulsen, Manuel Schiewe, Anca Sanda Mihaescu, Bogdan Ungur, Oliver Lemon, Simon Keizer, Marius Nicolae Popescu, Radu Tudor Ionescu, Cristina Cristalli, Giacomo Angione, Luca Lattanzi, Kari-Jouko Räihä, Howell Istance, Stephen Ackland.

This work has received the approval of the Ethics Commission of the: Teaching Emergency Hospital "Bagdasar–Arseni" (TEHBA), in Bucharest (no. 42493/ 19.12.2018), Teaching County Emergency Hospital "Sf. Apostol Andrei", in Galati (no. 27390/12.12.2019), The University of Medicine and Pharmacy (no. 137/20.12.2019), in Craiova and Balnear and Rehabilitation Sanatorium Techirghiol (no. 62/12.12.2019), Romania.

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