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Optimal model of transportation for people with disabilities: conceptual proposal designed in CAD

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Abstract. This study aimed to develop an optimal model of transportation for people with disabilities. To achieve this goal, powers of research and design should be involved, including CAD software. This paper investigates both: the concept of optimal model of transportation for people with disabilities (functional, ergonomic, constructive, technological and aesthetic solutions included); and its implementation as a fully-fledged 3D-model designed in SolidWorks environment. The optimal model of transportation is complex and consists of two objects. The first object is for indoors that is a wheelchair, the second one is for street driving that is an individual vehicle. The optimal model of transportation is universal and multifunctional, which have become possible with parametric feature-based approach utilized in SolidWorks.

Keywords: industrial design; SolidWorks CAD software; optimal model of transportation; people with disabilities; wheelchair; individual vehicle

1. Introduction

According to World Report on Disability (World Health Organization 2011) first published by the World Bank in collaboration with the World Health Organization, more than a billion people worldwide live with some form of disability; among them nearly 200 million have serious difficulties in the process of lifetime. Researchers forecast the prevalence of disability will increase in the future as a result of population aging, of increasing risk of disability will among the elderly, as well as global growth of chronic conditions such as diabetes, cardiovascular disease, cancer and mental disorders.

Disability is one of the components of human existence. Almost everyone in their lifetime can get temporary and permanent disruptions, especially common for the elderly. Anyway, to improve the life quality of people with disabilities, there are measures required to be taken at the national level and to be carried out by competent authorities. One such national measure is provision to disabled people special devices to ensure proper comfort while satisfying the relevant requirements.

An important lever for efficiency improving of this public policy course in relation to people with disabilities is industrial design, involved in almost all the levels of development and

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implementation of future objects of the appropriate purpose. One of the basic and urgent needs for people with disabilities is transportation, which will help to ensure complete integration and participation of people in the economic, social and cultural life of society.

Today in Ukraine the qualitative and quantitative level of this demand satisfying is at an early stage and needs organization and planning. To achieve these goals, powers of research and production should be involved, including industrial design tools. Thus, the optimal model formation for people with disabilities aimed at minimizing both forced dependence of the environment and to enhance the self-actualization and self-realization.

2. Literature review

2.1 Related terms

According to Standard Rules on the Equalization of Opportunities for Persons with Disabilities (General assembly resolution 48/96 1993), term "disability" summarizes a great number of different functional limitations occurring in any population in any country of the world. People may be disabled by physical, intellectual or sensory impairment, medical conditions or mental illness. Such impairments, conditions or illnesses may be permanent or temporary. Different expressions are used when referring to persons with disabilities and some of them have many implications in terms of representation. There are important distinctions between the terms "differently-abled persons", "impairment", "disability", "disabled people" and "handicap".

The term "differently-abled persons" indicates that disability is not perceived as a deviation from the norm. The World Health Organization, in its International Classification of Impairments, Disabilities and Handicaps (United Nations 2004), makes a distinction between these terms. The "impairment" term describes an abnormality or loss of a physiological structure or function. The "disability" term refers to the consequences of an impairment, it means lack of ability to perform some activity as considered appropriate. The "handicap" term means a social disadvantage that results from an impairment or disability. "Impairment" does not necessarily produce a disability and a disability need not be a "handicap" – the latter two terms are socially defined. For example, today poor eyesight is not considered a "handicap" because it can be corrected with eyeglasses.

According to Oskamp (1988), the term "disabled" is less desirable than "people with disabilities" because the former one implies that a person's disability is synonymous with the person him/herself rather than just one of many personal characteristics. That implication is deeply resented by people who know that they are much more than their blindness or missing limb. Moreover, the term "persons with disabilities" is consistent with the language used by the United Nations (UN). Dajani (2001) has revealed that disabling images are reinforced by the very language used to characterize disability. The labeling of people with disabilities categorizes them apart from the rest of the population, somehow more different than like others.

Longmore (1985) has studied that many terms could be described as medical labels in that persons with disabilities are often described as patients, cases, afflicted person or stricken with one condition or another. Regardless of the social situation, people with disabilities are often labeled and perhaps viewed primarily as objects of medical treatment but this is false understanding of positions.

2.2 People with disabilities

Disability, originally being medical term, is not a medical diagnosis, not at all. In fact, this term has sufficient social background which proves the following proposition of Convention on the rights of persons with disabilities (United Nations 2006) stated by UN: "Persons with disabilities include those who have long-term physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others".

In some ways, disability is a form of social inequality, which must be overcome somehow. First steps in this overcoming way are correctly formulated expressions usually used when referring to persons with disabilities, in particular the term "persons with disabilities".

The research showed that the conceptual and terminological apparatus of disability problem has no single and universal structure, so the concepts given in the information sources do not always reveal the required meanings. According to the "Instructions for determining disability groups" statements, approved by the Ministry of Health of Ukraine (Verkhovna Rada of Ukraine 2017), the concept of "people with disabilities" is assigned, being comprehensive and neutral in appeal.

2.3 Transportation of people with disabilities

Terminological analysis revealed the main point for further research and that is transportation which appears to be one of the key elements of rehabilitation processes for people with disabilities. Rehabilitation is intended to restore and unleash the physical, mental and social potential of people with disabilities as well as ensure their complete integration into a social life. The special mobility assistance for transportation is needed such as wheelchairs, individual vehicles, etc. Being streamlined by rehabilitation technologies, these objects are at the interdisciplinary interaction between medical, socio-economics and human sciences. So, the design of such object, supported by relevant interdisciplinary data, can be aimed not only at providing transportation itself but also present a multifaceted solution to this problem in various conditions.

In general, the transportation of people with disabilities can be divided into two main levels: internal (short distances) and external (long distances). Each level has its own area and corresponds to its special mobility assistance. Internal level includes transportation within the premises, both residential and public. These kinds of travel are mainly provided with wheelchairs, rollators, etc. External level involves city driving, from place to place, etc. In this case vehicles are used, which, in contrast to objects of the internal level, are represented by a smaller number of design proposals.

It should be noted that recent development and production of innovative mobile equipment have revealed yet another level, which can be described by the general term "universal". The semantic content of this level involves other way to organize the mobility of people with disabilities using universally applicable objects. They are exoskeletons and artificial prostheses, which can be considered as "natural continuation" of user's upper and lower limbs, providing mobility in various conditions. The impossibility of explicit correlation of these objects with the internal and external levels specifies its universalization.

Professional literature dedicated to transportation of people with disabilities in two main areas is analyzed: Conceptual solutions and already implemented projects, including wheelchairs and other mobility assistance described by Popovic (2019). The main achievements in design of such vehicles are focused on self-driving mobility so the human efforts are reduced. Anti-collision

Table 1 Classification of vehicles for people with disabilities

Transport device	Type of drive	Functional purpose
Wheel transport device	Muscular drive (biohydrogen, fuel element, cell battery)	Internal level (wheelchair, rollator)
Track-type transport device	Electric drive	External level (private and public vehicles)
Walking transport device	ICE drive (internal combustion engine)	Universal level (prosthetic appliance, exoskeleton)
Hybrid transport device	Alternative drive (bicyclic, lever and hoop types)	
Conceptual and futurological transport device	Hybrid drive	

sensors, adaptive switches, control devices and other mounting solutions have become an integral part of smart mobility assistance.

According to the domestic and foreign production analysis, the classification of vehicles for people with disabilities is developed and shown in Table 1. The basis of classification is represented by wheel and non-wheel vehicles, clustered in dependence on the configuration of the drive and its technical saturation. The functional purpose represented by internal, external and universal levels is also included. Another important aspect of transportation is specially designed barrier-free environment so that users were able to accomplish all tasks with ease. The impacts of ergonomics and other human factors of wheelchair/user combinations on effective barrier-free environments have been studied on the example of rail coaches (Xiang *et al*. 2018).

Despite the large number of design proposals for transportation of people with disabilities, most of them reveal certain aspects of mobility, for example only indoor moving or outdoor driving. At the same time, integrated and complex solutions of full-time mobility in different environments currently not actually represented.

3. Optimal model of transportation for people with disabilities

According to the presented classification of vehicles, the major factors affecting the object shaping for people with disabilities are identified as follows:

– Functional factors
– Ergonomic factors
– Constructive and technological factors
– Aesthetic factors

Functional factors, first of all, involve the necessity of stairs and bordure overcoming as well as overpassing other obstacles. Sitting position of person with disability is not enough for the entire household needs, so body regulation during the day is crucial especially indoors; driving on unstable surface is useful for outdoors. Another functional factor is all-season suitability of transportation, including long distance travelling.

Ergonomic factors focus on optimizing all the regulations and transformations of potential vehicle taking into account its constant interaction with person with disability. It also implies the

Fig. 1 First object of the optimal model of transportation

regulation of minor constructive volumes and their design consistent with the human anatomy.

Constructive and technological factors assume the reasonable structure of potential vehicle with transformation ability; unification of parts and assemblies; optimal control system. Material and technology selection is also important when it comes to both primary and secondary constructive components. Careful work with construction is a key element for safe usage and long-lasting duration of operating life.

Aesthetic factors involve the artistic expressiveness of potential vehicle because the prevailing "stereotypical" morphology is usually not supported by components of artistic solution. The selection of colour and texture also brings certain aesthetic value as well as plastic detailing with more nuanced criteria of artistic composition.

Further consideration of optimal model of transportation for people with disabilities is based on solutions corresponding to the factors mentioned above. The basic concept of the optimal model of transportation consists of two objects. The first object is for indoors that is a wheelchair, the second one is for street driving that is an individual vehicle.

Both objects being complex industrial products were designed in SolidWorks computer program, notably by using solid modelling Computer-Aided Design (CAD).

3.1 Functional solution

The functional capabilities of two objects are planned and organized according to functional factors. Wheelchairs must assure descent/ascent stairs climbing and overpassing other obstacles. These requirements are satisfied with "Galileo Wheel" construction of the wheelpair designed by "Galileo Wheel" company (Jerusalem, Israel). The minimal set consists of one pair, with one primary wheel and one auxiliary, that is inside of the primary in the folded state and spreads out of the boundaries in unfolded state to form a track.

In the very moment the system of levers begins to move in different directions. Each lever ends up with an auxiliary wheel, which pushes on the rubber wheel rim from inside. Tyre configuration is changing under this force, so it transforms to the shape of trapeze.

Other technical solutions of wheelchairs with stair climbing ability were also considered. The

(a) Closed state (b) Opened state

Fig. 2 Transformation of "Galileo Wheel" with two wheelpairs

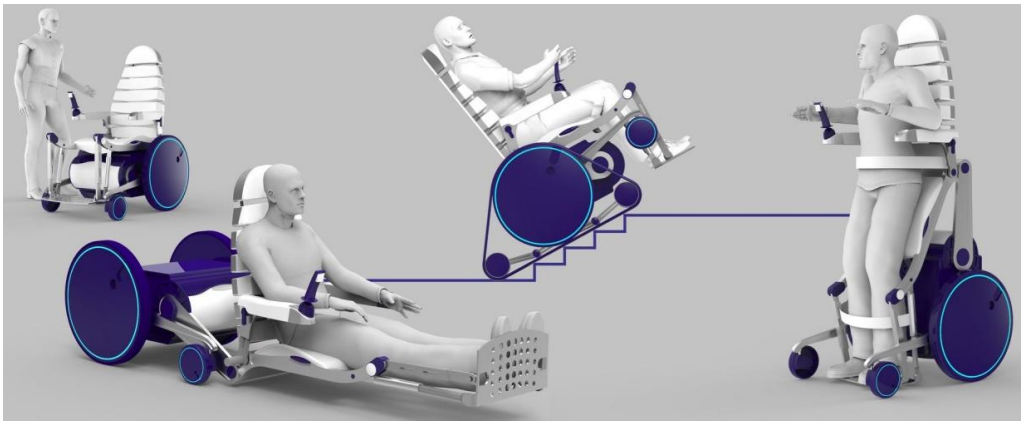

Fig. 3 Possible positions of the wheelchair

wheelchair, described by Quaglia and Nisi (2017), is able to climb single obstacles or staircases thanks to a hybrid wheel-leg locomotion unit with a triple-wheels cluster architecture. Hinderer *et al*. (2017) have developed an autonomous stair-climbing wheelchair based on a leg mechanism that consists of two legs with lower and upper leg support. Chocoteco *et al*. (2015) have presented Stair-Climbing Mobility System (SCMS) that combines two different locomotion mechanisms to climb up and down stairs: one based on wheels and the other based on Sliding Supports.

These technical solutions are quite efficient but suitable mainly for indoor use while "Galileo Wheel" construction of the wheelpair has more universal tyre configuration for both indoors and outdoors.

An expedient solution for designed wheelchair, shown in Fig. 1 is an implementation of "Galileo Wheel" with two wheelpairs, consisting of one primary and two auxiliary wheels, which spread out symmetrically during the transformation. The transformation of this wheelpair is designed in SolidWorks environment and shown in Figs. 2(a)-2(b). This functional solution allows not only stairs ascending and descending, but also ensures stability of this process as well as enables free driving on gravel and sand.

Also, universality and multifunctionality of the wheelchair is due to its ability to transform to a different position states, so the spatial body shift is possible. To perform this, an energy block with counterweight system comes in motion, rotating of which on the main axis shifts other components of the wheelchair on special rails. Among the possible positions, shown in Fig. 3,

Fig. 4 The arrangement of the person with disabilities inside the vehicle

there are:

• A normal sitting position

• A vertical position (communication with other people, possibility of taking goods from the upper shelves in supermarkets, payment terminal usage convenience, buying foods in special automatic machines, etc)

• A horizontal position (necessity of changing body position, ability to pick up an object from the ground, comfortable pastime on the rest, etc)

One more functionality of the wheelchair is a maintenance of medical massage actions, by means of the built-in rollers system, located in a backrest and in the seat of the wheelchair.

For driving outside of premises, the individual vehicle capability of an arrangement of the disabled person together with a wheelchair in salon is necessary.

The important functional factor of individual vehicle usage is all-season suitability, a possibility to use it at any season and in any weather conditions. Thereof, for performing a full value transportation of the person with disabilities, an individual vehicle with the closed body is needed.

The main function of the second object of the optimal model formation for people with disabilities is moving on long distances. Proceeding from this function, it is also necessary to provide a process of an arrangement of the person with disabilities in electromobile salon. The algorithm of this process is simple enough and shown in Fig. 4: Opening of a door of an electromobile is activated by means of remote control, thus there is an automatic lowering of a special ramp for loading and placing of the wheelchair in salon.

The distinctive feature of the proposed design solution is unification of control systems, both the wheelchair and the individual vehicle, it can be reached by use of the demountable joystick with a standard socket, which is removed from one object (wheelchair armrest) and is installed in the other object (vehicle control manipulator).

3.2 Ergonomic solution

Conformity of the object's project proposals to ergonomic requirements and recommendations is analyzed. Ergonomic solution of the seat and backrest profiles of the first object of the optimal model of transportation – wheelchair allows the human spine to take natural S-profile position. Fig. 5 shows that basic shaping line of the backrest and seat lies within the parameter's zone

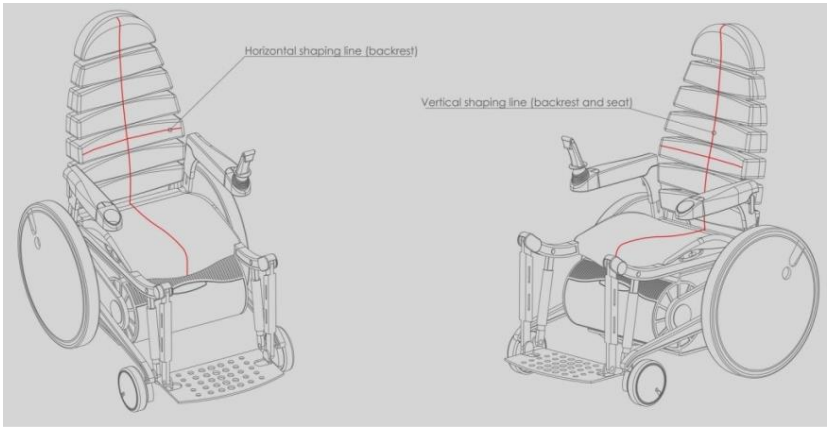

Fig. 5 Shaping lines of the backrest and seat with parameters provided by B. Akerblom

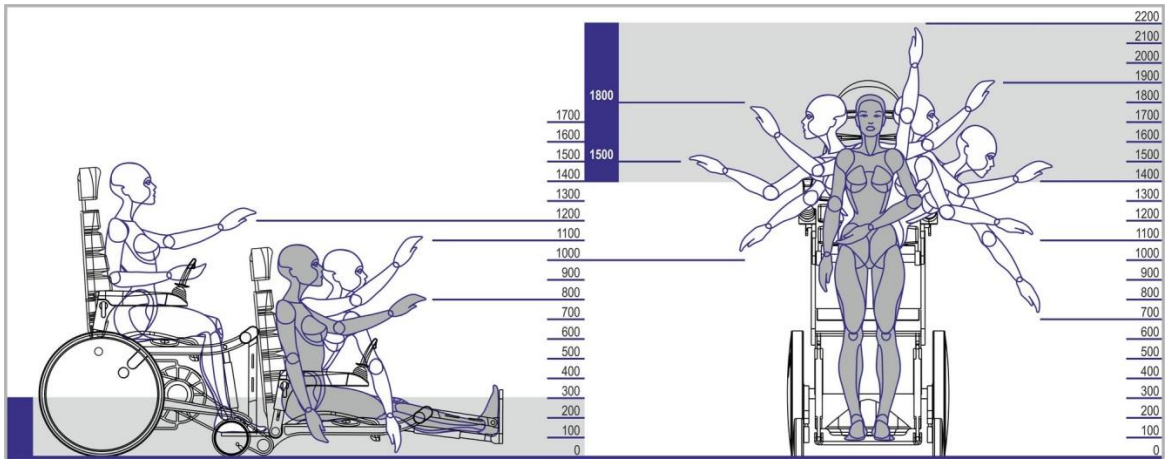

Fig. 6 Ergonomic scheme of the wheelchair

provided by B. Akerblom and most consistent with the human anatomy. The seat of the wheelchair was designed according to weight concentration of potential user, which has been studied by special measurement and analysis (Nageswaran *et al*. 2018).

A possibility of tuning for all of the constructive volumes are taken into account, such as: backrest slope, headrest and armrest height setup. A flexible system with handy regulation allows the maximum adaptation of jointed surfaces to anthropomorphous characteristics of each individual. Also, the system of fixation for a person with disabilities in the wheelchair is planned, as it is necessary for the wheelchair transformation process and for the user position change. As basic guides for design both the wheelchair and individual vehicle the ISO standards “Assistive products for persons with disability” (ISO 9999:2016 2016) and “Wheelchair containment and occupant retention systems for accessible transport vehicles” (ISO 10865-2:2015 2015) were used. These standards gave specific understanding of accessibility and prompted the decision to choose “Galileo Wheel” construction of the wheelpair. The selected wheel design in combination with the energy block eventually resulted in solution concerning more flexible accessibility of the wheelchair as shown in Fig. 6.

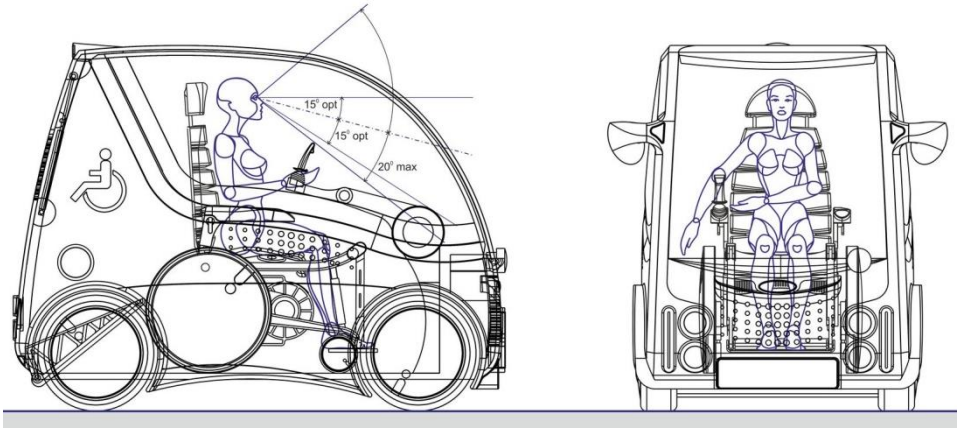

Fig. 7 Ergonomic scheme of the individual vehicle

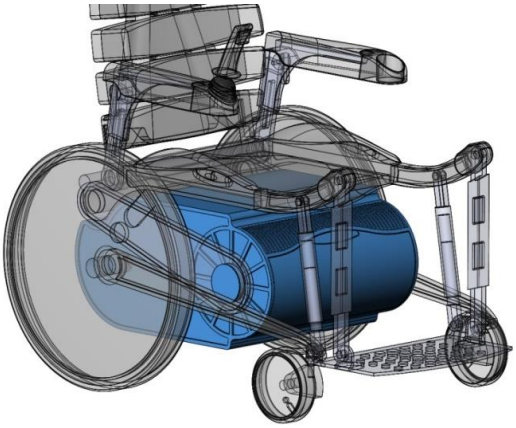

Fig. 8 The energy block of the wheelchair

Fig. 7 shows the dashboard of the second object of the optimal model of transportation – individual vehicle, which is developed according to the working zones subdivision. Shaping of the windshield and side window, as well as their arrangement in the global structure of a car body provide an optimal field of view in the external environment for a disabled person.

3.3 Constructive and technological solution

The structural and technological solutions of the wheelchair are based on the "Galileo Wheel" technology. The energy block is also a main constructive component of the wheelchair, shown in Fig. 8. The wheelchair is equipped with electrical drive and powered by batteries, and the control joystick is built in the armrest, so it can be installed for the left or right hand without any loss of functionality. A motion control algorithm (Choi *et al*. 2019) that can improve the safety and riding comfort can be used in this regard.

Every detail of optimal model of transportation is designed in SolidWorks environment on a scale of one to one. These details are arranged in special assembly, so the spatial transformation is

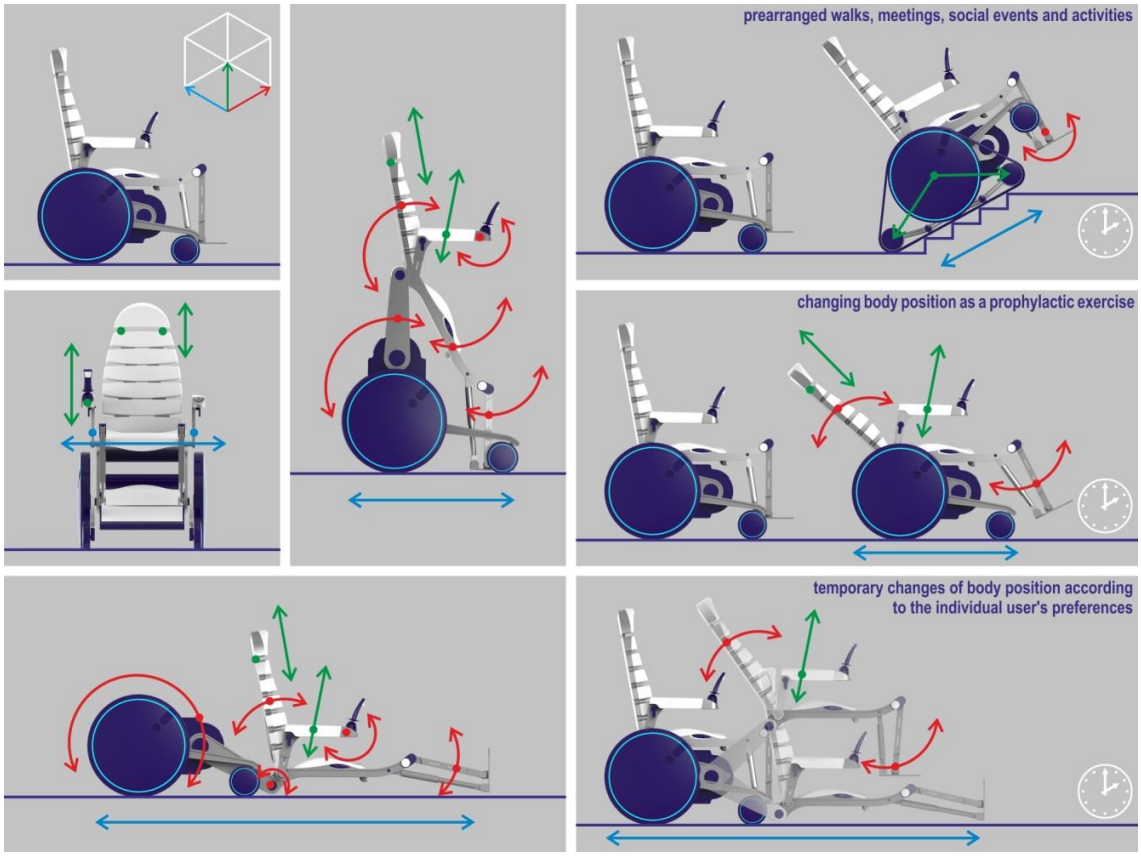

Fig. 9 Transformation of the wheelchair into different positions and within a specified period of time

possible. In the wheelchair it also includes adjustable seat and backrest, leg and arm rests, which provide easy adaptation to the specific needs of the individual users. Possible transformations are shown in Fig. 9. It also represents more complex situations when transformation of the wheelchair is set within a specified period of time. To ensure the safety of user while transforming the counterweight system is provided in lower part of the energy block. This system balances body shifts in space. The wheelchair is also equipped with front wheels which stabilize its transformed structure and users' position.

To improve the efficiency of massage procedures the application of special viscoelastic, anti-decubitus materials for wheelchair upholstery is reasonable. The memory foam for the internal filling and waterproof materials for the cover are easy to clean. In case the function of therapeutic massage has not been used, the provided output for the control unit can be closed with special decorative pad.

For nowadays, the feature of the majority of wheelchairs, irrespective of a variety of their functionality, discrepancy of art searches of the shape to the constructive and technical solution takes place. Specificity of the purpose of the wheelchairs really assumes careful work with construction, because the competent technical solution of such objects is necessary for safety of a person with disabilities during movement, for comfort and duration of operating life.

The second object of the optimal model of transportation – individual vehicle, is driven by two

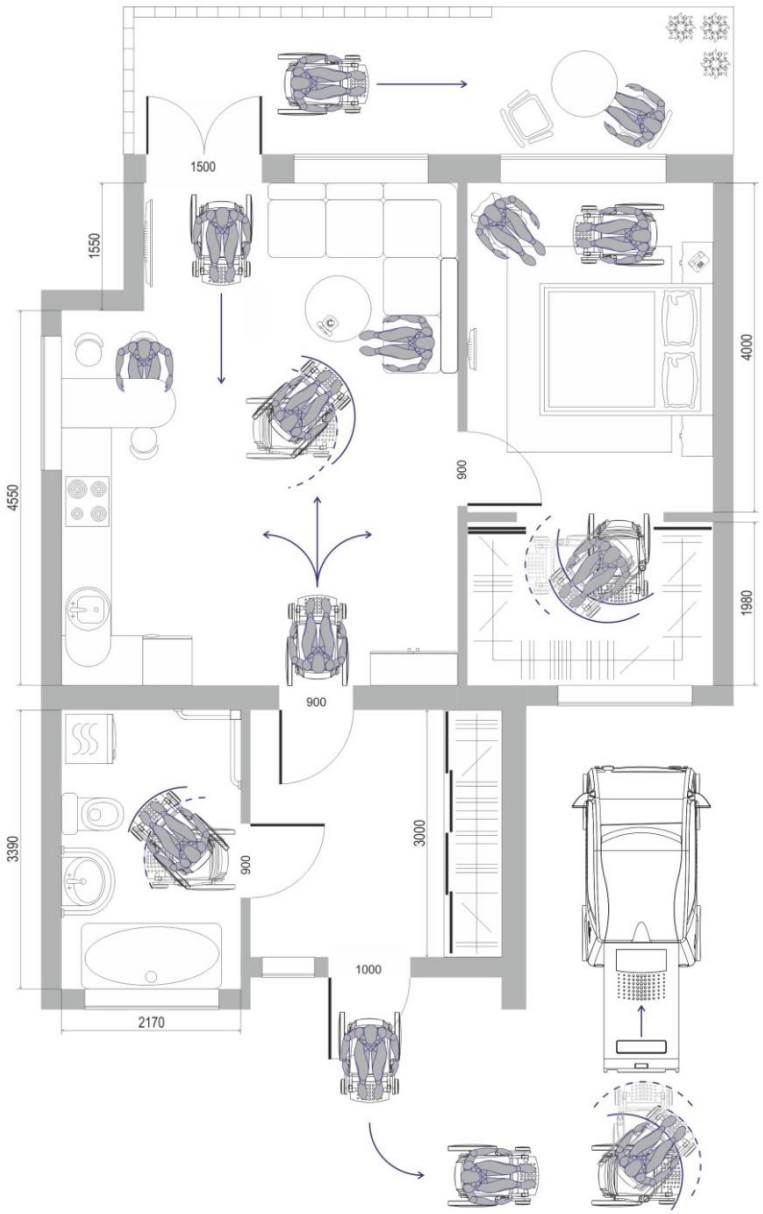

Fig. 10 Graphical analysis of optimal model of transportation in the house

motor-wheels. There is a carcass-panel principle used in construction of the car body – the carcass is made of aluminium and skinned with polymer panels. The wheelbase of the individual vehicle has been selected from the compact car class segment. Realization of the constructive solution of the optimal model of transportation for disabled people presupposes the progressive technologies and the use of modern materials.

The ventilation system in the cabin is represented with lattice's raster array on the front, back and lateral sides of the individual vehicle body. In case of extremely hot weather, additional

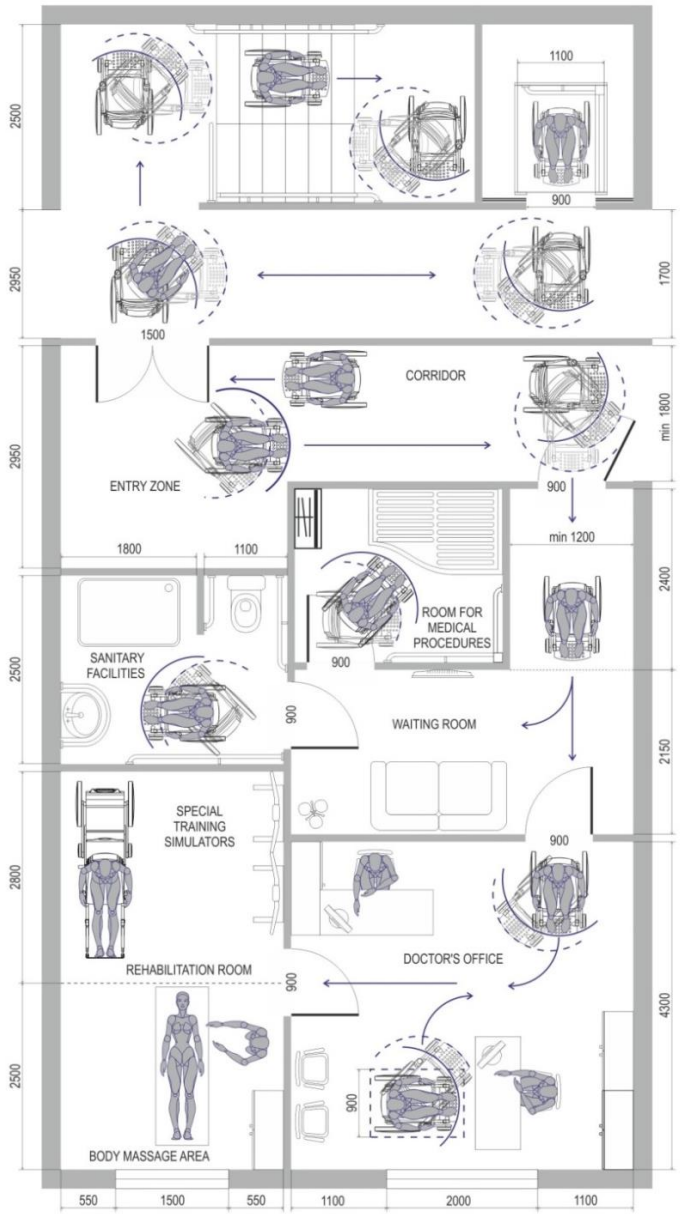

Fig. 11 Graphical analysis of optimal model of transportation in medical center

ventilation of the cabin can be provided with opening cap located in the roof. The constructive solution of the roof also includes a removable emergency hatch with a special connector. In case of a traffic accident and the vehicle overturning, it is necessary to pull the connector and remove the top cover; the resulting space will allow removing a person with disabilities from the cabin.

The constructive and technological solution of the optimal model of transportation is rather conceptual, so before the launch of production further technical development of element base, structural units and manufacturing technologies is needed.

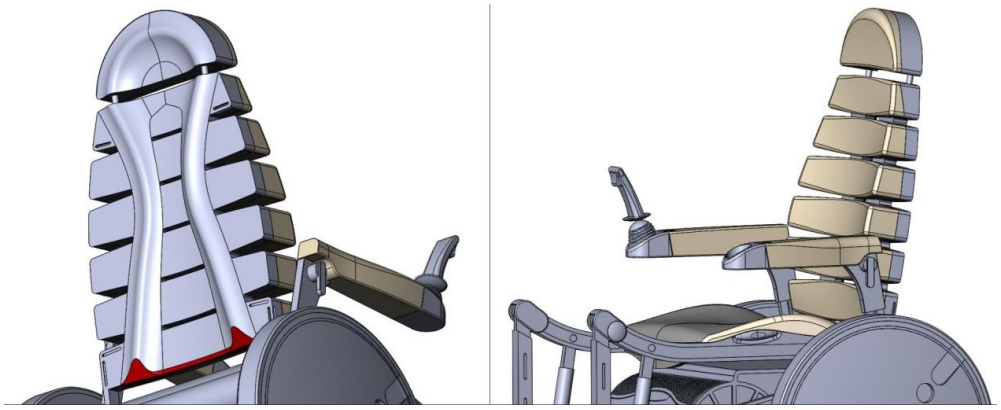

Fig. 12 Design solution of the backrest and the seat

Some cases of user's movement in different life situations were simulated schematically by drawing tools of SolidWorks program. They represent graphical analysis of optimal model of transportation for people with disabilities on the example of conceptual house and medical center (see Figs. 10 and 11).

At the same time, the excessive technical saturation, which has been not supported with components of the art-shaping solution, doesn't promote to expressive design and causes proof associations with uninteresting shaping of the wheelchairs. In this connection, the special attention in the wheelchair design process has been paid to its design solution, an attempt to create a modern and attractive image, which evokes positive emotions, both for the user, and for associates.

3.4 Aesthetic solution

The design solution of a backrest of the first object is made in unusual way for wheelchairs, and represents the smooth two-private segments, penetrated by a sculpturesque line, as an original interpretation of a human backbone. The anthropomorphous contour of the seat is finished with the adjustable headrest, which visually "rounds off" segment formations of the front side, and serves as an ansiform solution of the back side's sculpturesque line, even more underlining its bend and grace. Tabl 12 shows that despite of a multicomponent structure of a backrest, the integrity of its visual perception is not broken.

The shaping of the individual vehicle, shown in Fig. 13, is done according to the modern tendencies in automobile industry and is presented by smoothly flowing volumes with actively expressed bearing that gives dynamism to a volume-spatial structure of an electromobile. The proportional ratio of a body details and a glass cover is structurally justified, guiding glass planes take the dynamic support in a raster dot elements arrays of the ventilating lattices on all the planes of the vehicle. Actively expressed wheel arches emphasize with the electromobile's belonging to automobiles family.

The front panel of the electromobile represents "a friendly user interface" thanks to the shape-building lines of an air intake with corresponding dynamics of the dot elements of the ventilating lattice raster. Lighting elements are "winking" to the user, and curvilinear lodgement for the wiper keeps "smiling" shape of an air intake. All these elements are intended to reveal positive emotions of the person with disabilities.

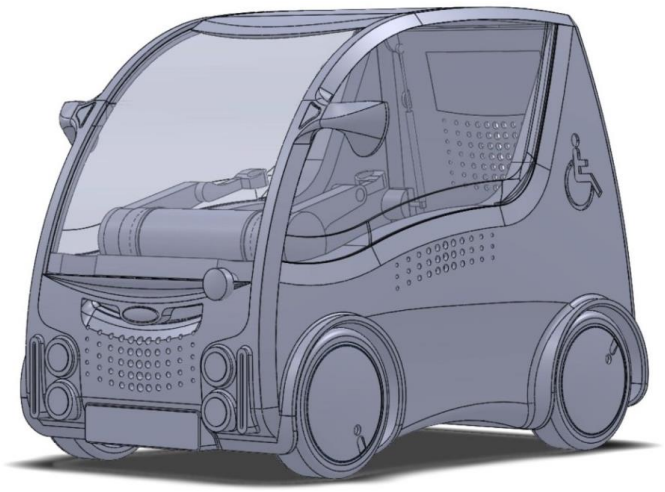

Fig. 13 Second object of the optimal model of transportation

Placing of the pictograph with the picture of the disabled person on the side and back parts of the electromobile, performed in corresponding to colour-texture solution with a night-time illumination, will help to identify the disabled persons on roads to increase the safety as a participant of traffic, and to exercise an adequate, predictable reaction of the other road traffic participants.

First of all, it is a colour-texture solution, which components are presented both in the wheelchair and in the individual vehicle. So, the basic volumes are accented by white shades and auxiliary – by dark blue colours. Such a colour-texture solution is an effective way for maintaining the indivisibility of objects and their intrinsic similarity. Implementation of the elements with the identical compositional, sculpturesque and colour-texture solutions for decorative wheel caps, performed in different overall dimensions, but in identical proportional ratios emphasize once again their collateral subordination. Each cap, irrespectively of belonging to the first or the second object of the optimal model of transportation is equipped with a light-emitting diode border, which creates an interesting visual lighting effect during the driving. Also, certain interrelation of two objects is created by stylistic inter-addressing in certain details, particularly in rhythmical dynamics of the dot elements, presented in the perforated solution of a feet support in the wheelchair and in the shape of ventilating lattice's raster array on the lateral sides of the individual vehicle body. Collateral subordination of two objects of optimal model of transportation for people with disabilities, their complete perception as one system is reached with correspondence to aesthetic factors.

At the same time, determining the aesthetic factors of three-dimensional design, in other words, the level of aesthetic in this type of artistic and practical activity is a big and complex problem that deserves separate consideration. In fact, there are no strict criteria for "measuring" the levels of aesthetic and it cannot exist in principle, because the aesthetic is a characteristic of the relationship between the subject and the object. Evaluating the finished product's design is a subjective task in nature (Ulrich and Eppinger 2011).

The subjective component is variable: since all subjects of aesthetic perception, as well as creativity, differ by lot of parameters, there can be no objective criterion for the level of aesthetic.

4. Conclusions

The concept of optimal model of transportation for people with disabilities has been proposed in this study as well as its implementation in a fully-fledged 3D-model designed in SolidWorks environment.

- The optimal model of transportation is complex and consists of two objects. The first object is for indoors that is a wheelchair, the second one is for street driving that is an individual vehicle. Both objects are complex products of industrial design so CAD system with parametric solid modelling capabilities is needed. The most appropriate one is SolidWorks with its modelling, visualization and drawing tools. Special 3D-model assemblies with correctly arranged details allowed simulation of every possible transformation of both: wheelchair and an individual vehicle. Transformational processes in turn revealed a number of functional and ergonomic advantages while maintaining appropriate comfort for people with disabilities.
- SolidWorks modelling tools were primary during the constructive and technological design of optimal model of transportation. Basic and additive options of "boss/base", "cut" and "features" palettes represented in SolidWorks environment provided all necessary shaping measures for "Galileo Wheel" construction of the wheelpair. The proposed aesthetic solution of optimal model of transportation has a sufficient art expressiveness and originality, creating a catchy image, and emphasizing the specific mission of objects.
- Thus, the volume-spatial structure of the offered optimal model of transportation for people with disabilities and its nuance detailing in combination along with the colour-texture solution allows to assert that the given problem can be solved by means of industrial design and in particular by means of SolidWorks. Developed by means of industrial design, the optimal model of transportation for people with disabilities will help to fully integrate a person with disabilities into the social life.
- This study represents the concept of optimal model of transportation for people with disabilities aimed at providing both systemic organization and comprehensive solution to the issue of transportation, compared to mostly separated design projects characterized by local tasks, along with the limitations when calculating the ultimate product cost. There's a possibility that both objects of optimal model might prove unaffordable for the majority. In this case optimal model of transportation can be a part of grant programs provided by foreign foundations and charitable organizations. Another limitation is of regional nature. Small-sized stairwells typical for panel housing in cities of the post-Soviet space, particularly in Kharkiv (Ukraine) are inappropriate for the large-sized wheelchairs so the transformation of first object can be limited. Moreover, not well-developed infrastructure of these cities also put limits on the use of electric vehicles (second object) by lack of charging stations. The proposed optimal model of transportation is rather conceptual, so before the launch of production further technical development of element base, structural units and manufacturing technologies is needed.

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