A Systematic Approach to Support Conceptual Design of Inclusive Products

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Abstract. Over the last years, several approaches have been defined to support Universal Design. However, a method that allows supporting universal design process in a systematic way is still lacking. Consequently, very often, products are merely designed according to design guidelines, without considering their effective context of use, while the success of products is often determined by the experience, intuition and sensitivity of designers, rather than by a real good design practice. In this context, the paper propose a systematic approach to support the conceptual design of modular and adaptive products, where for products we mean any device, tool, artefact, building, or service.

Keywords: User-centered design · Ability-oriented design · Human factors · Universal design · Adaptive systems

1 Introduction

Designing successful inclusive products is a big challenge: it means designing products that while having "special functions" for some perceptual, cognitive and/or physical abilities should be equal or more attractive and usable than common products. Literature overview highlights a lack of structured, repeatable and systematic methods to drive the designers from preliminary research to the identification of an effective, acceptable and usable solution for a wide range of users. The present research work tries to find an answer to the following question: is it possible to define a systematic approach to develop inclusive products that could be a basis for innovative design methodologies?

Firstly, what characterize an inclusive design process is that it addresses the widest possible range of end-user needs, according to an user-centered perspective. Consequently, its outcome, as observed by Emiliani [1], "(…) is not intended to be a singular design, but a design space populated with appropriate alternatives, together with the rationale underlying each alternatives, that is, the specific user and usage context characteristics for which each alternative has been designed."

Secondly, the implementation of inclusive design paradigm requires:

- To acquire knowledge about the capabilities, needs and goals of potential users and about all possible scenarios in which people will use products, systems or services;

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- To define effective tools and techniques to synthetize all collected information, to elaborate it in an effective and comprehensive way (problem framing) and to formulate a proper list of requirements;
- To identify an operational and systematic methodology to conceptual design.

Over the last years several approaches have been defined to support the design of universal products, which includes several principles and guidelines [2], or method and tools [3]. They can useful to carry out several design process stages (e.g. context of use analysis [4], evaluation of design solution [5]). However, it has not yet been developed a method that allows to support the conceptual design of a universal project in a systematic way.

In this context, the present paper proposes systematic approach to support the conceptual design of modular and adaptive products, where for products we mean any device, tool, artefact, building, or service. The proposed approach has been applied to the re-design of a kitchen environment, in order to make it more inclusive, especially for people in wheelchair. However, it is general enough to be applied in several design context (e.g., Interaction Design, Industrial Design and Service Design).

2 Research Background

In the last years, several approaches has been proposed to support the design of universal products. The first tentative to conceptualize UD was carried out at the Center for Universal Design of North Carolina State University through the definition of seven design principles: Equitable Use, Flexibility in Use, Simple and Intuitive Use, Perceptible Information, Tolerance for Error, Low Physical Effort and Size and Space for Approach and Use [6]. These principles soon became an integral part of the concept of UD and so, many products have been developed based on this paradigm [7, 8]. However, as observed by Kostovich et al. [9], they represent only high-level guidelines, so they are more usable as an evaluation aid that as a design tool. In fact, their effective application in an industrial context is very hard to achieve because they require to designers to proactively focus on the ability of product features to satisfy users with different characteristics and needs. This is very difficult to achieve for designer, because they are used to working reactively: they are good at finding solutions according to a definite set of project requirements. Moreover, designers usually are unaware of characteristics, needs and preferences of customer with physical and mental disabilities, so that they may take incorrect assumptions about effective users' abilities: this let to design exclusion. According to Keats and Clarkson [10], design exclusion occurs when there are discrepancies between requirement demands and product demands because designers have introduced product features, that are not essential attributes of the product, requiring new capability demands to the users.

To avoid exclusion and support design of more inclusive products, Keats et al. [11] propose a 5-level approach, based on existing usability techniques, user-centred design practice and user modelling methods. In the context of universal design this approach is definitely the most structured one, although it merely defines the various steps that should characterize the design process and lists the methods that can be adopted to support the various phases, without effectively support their choice. Furthermore, it is mainly intended to ensure the accessibility of the product, and therefore it is not able to support the management of complexity of a universal project in a comprehensive way. For example, since it is based on a traditional user-centred design, it tends to neglect the dynamic nature of users abilities and it seems more oriented to products and systems which are static or which have very limited means of adapting to the changing needs of users as their abilities change.

To consider the user in a more comprehensive way, Newell and Gregor [12] suggested the use a new methodology, entitled "User Sensitive Inclusive Design" (USID). The peculiarity of USID is that it considers the dynamic nature of user characteristics and functionalities, both in short and long term, and it takes into consideration that they can be also affected by the context [12]. Furthermore, USID aims to support designers to develop an empathy with older and disabled users. Whereas it is impossible to produce a small set of users who were truly representative of the whole population, this approach suggest defining of "extra-ordinary users" profiles [13]. To define such profiles the use of Persona approach is suggested. In general, a Persona is a realistic description of an abstract person, who represents a group of real target users of the product with common characteristics and needs [14]. Accordingly, an "extra-ordinary user" should be considered as an "individual person who happens to have a specific disability, as well as a range of other characteristics which are important for defining them as a person, but may not be related to their disabilities" [13].

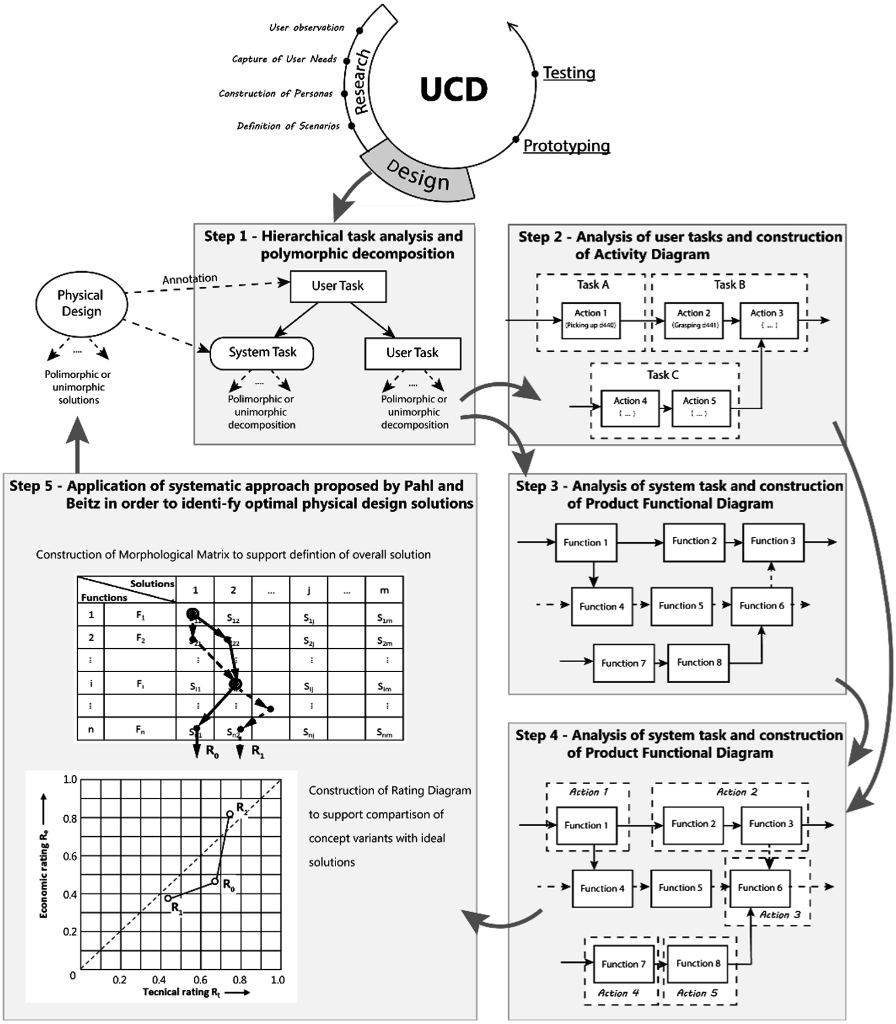
Finally, to support the design of products able to accommodate users' variability, the approach known as Ability-based Design has been developed in the context of ICT products [15]. Ability-based design promotes the development of personalized user interfaces that adapt themselves or can be easily adapted by the human user. Among the proposed method, the Unified User Interface Design Method proposed by Savidis and Stephanidis [16] is the most systematic one, although it cannot be considered totally systematic. In fact, although it provide a tool to analyse the design problem in terms of tasks that must be fulfilled by the system or by the user, it is not able to properly support the definition and selection of design solutions, since the conception of solutions is delegated to the intuition and/or experience of designers. Consequently, it seems to work very well in the context of SW design, where system functions are very closed and related to system functions at a level of fine detail, and where many design guidelines have been defined to ensure SW quality (e.g., accessibility, usability, etc.). This limitation may prevent its adoption in other design contexts (e.g., industrial design), where precise and detailed design guidelines have not been yet defined.

Based on our knowledge, the more systematic approach described in literature is that defined by Pahl and Beitz [17]. Such method introduces product functional analysis to support the definition and evaluation of the most reasonable design solutions in an objectively way, without relying on the skill of the designer. However, this method, developed in the context of Engineering Design, does not consider the interplay between user and product in analyzing design problem and defining design solutions, so that it is difficult to apply it in the context of universal design.

Therefore, despite the significant effort made to improve UD, a systematic design approach that designers can use in several design context does not exist today. Another weaknesses is due to the strong targeted nature of all the approaches, both in terms of application context and design objectives (e.g., universal design most concerns architectural design context, inclusive design mainly supports industrial product design, ability-based design aims to support the design of software applications, etc.).

3 The Proposed Approach

The approach that we propose to use aims to interrelate the UUIDM with the systematic approach proposed by Pahl and Beitz by using Action-Function Diagram (AFD) [18] (Fig. 1).



Functions \ Solutions		1	2	...	j	...	m
1	F_1	S_{11}	S_{12}		S_{1j}		S_{1m}
2	F_2	S_{21}	S_{22}		S_{2j}		S_{2m}
⋮		⋮	⋮		⋮		⋮
i	F_i	S_{i1}			S_{ij}		S_{im}
⋮		⋮	⋮		⋮		⋮
n	F_n	S_{n1}	S_{n2}		S_{nj}		S_{nm}

Fig. 1. The proposed approach

It is based on the following steps:

1. Hierarchical task analysis and polymorphic decomposition according to the UUIDM approach [16]: the polymorphism concept provides, to the hierarchical task analysis, the capability to represent, at the same time, different way, or style, to perform the same task at any level of the task hierarchy, according to particular user- and usage-context attribute values. In general, polymorphic decomposition occur when more styles are mutually compatible, so that the solutions can be define as a combination of design instance.
2. Analysis of user tasks identified in the first step and construction of related Activity Diagrams. To this purpose, User Activities can be modelled according to the ICF lexicon [19], by using domain related to body function and activities, which are most important for interaction design [20–22] (Table 1).

Table 1. Human abilities relevant for design defined as a sub-set of ICF domains

Human abilities relevant for design		*Correspondents*	Related ICF domains	
Hearing	Abilities in perceiving auditory stimuli	*Tone, volume, language, words, source, rhythm*	Sound detection (b 230)	Hearing (b230–b2309)
			Sound discrimination (b 2301)	
			Localization of sound source (b 2302)	
			Lateralization of sound (b 2303)	
			Speech discrimination (b 2304)	
Vision	Abilities in perceiving visual stimuli	*Shape, contour, gaze angle, resolution, colour, light, contrast, see on short or long distances*	Visual acuity function (b2100)	Seeing and related functions (b210–b229)
			Visual field function (b2101)	
			Quality of vision (b2102)	
Cognition	Abilities in receiving, comprehending, interpreting, remembering, or acting on information	*Mental stimuli, level of attention, engagement, remember (short and long term), semiotic and semantic abilities, thinking ability*	Attention of functions (b140)	Specific mental functions (b140–b189)
			Memory (b144)	
			Mental function of language (b167)	
			Thought functions (b160)	
		Emotional level, sensorial stimuli control	Perceptual function (b156)	
		Motion control, coordination	Psychomotor function (b147)	
			Mental function of sequencing complex movement (b167)	
Speech	Ability to speak	*Pronounce vocal command*	Voice and speech functions (b310–b399)	

(*continued*)

Table 1. (*continued*)

Human abilities relevant for design		*Correspondents*	Related ICF domains	
Body functions	Abilities in performing common tasks with the body		Vestibular functions (b235–b249)	
			Pain (b280–b289)	
		Maintaining a body position, maintaining a lying position, maintaining a squatting position, maintaining a kneeling position, maintaining a sitting position, maintaining a standing position, maintaining a standing position	d 415 Maintaining a body position	Changing and maintaining body position (d410–d429)
		Transferring oneself while sitting or while lying	d 420 Transferring oneself	
		Lying down, squatting, kneeling, sitting, standing, bending, shifting the body's centre of gravity	d 410 Changing basic body position	
Mobility	Abilities required to perform common tasks related to mobility	*Walking short distances, walking long distances, walking on different surfaces, walking around obstacles*	d 450 Walking	Walking and moving (d450–d469)
		Moving around using equipment	d 465 Moving around using equipment	
Arm functions	Abilities in upper and lower extremity range of motion, coordination, and strength	*Pushing with lower extremities, kicking*	d 435 Moving objects with lower extremities	Carrying, moving and handling objects (d430–d449)
		Lifting, carrying in the hands, carrying in the arms, carrying on shoulders, hip and back, carrying on the head, putting down objects	d 430 Lifting and carrying objects	
		Pulling, pushing, reaching, turning or twisting the hands or arms, throwing, catching	d 445 Hand and arm use	
Hand functions	Abilities required to perform common tasks related to hand function	*Picking up, grasping, manipulating, rel*	d 440 Fine hand use	

3. Analysis of every system task (or style) identified in the first step and construction of related Product Functional Diagram, according to Functional Basis and the associated flow-based functional modelling methodology [23, 24].
4. Construction of Action-Function Diagram (AFD) to highlight the functions of product in which the user is directly involved. AFD allows the integration of Activity Diagram within the Functional Model of the product/system, so that it enables to represent user-product interaction [18].

5. Application of systematic approach proposed by Pahl and Beitz in order to identify optimal physical design solutions. Pahl and Beitz [17] to support definition of possible solutions and to select them according to determined evaluation criteria have proposed several selection and evaluation methods. In particular, to define the overall solution as systematic combination of possible design principle, the construction of a morphological matrix con be useful. In general evaluation can involve the assessment of technical, ergonomic and economic values. The evaluation may involve the comparison of concept variants or the determination of their rating or degree of approximation of the ideal solution. In this last case, the construction of a Rating Diagram can be useful.
6. Construction of a Unified Task Diagram to synthetize and put in relation design solutions to each other.

4 A New Inclusive Concept of Kitchen

The proposed approach has been applied to the redesign of a kitchen environment, in order to accommodate needs of user with different typologies, and levels of motor disability. This choice is motivated by the results of the analysis of existing solutions intended for users with different levels of motor disability. In fact, most popular solutions, in the face of adequate accessibility and functionality, according to ergonomic requirements, present an esthetic design too far from the “typical” kitchen. They merely was design for “ensure ergonomics” and are not able to give a sense of familiarity and pleasure for all. So, they do not embrace the aims of Design for all: they result unattractive for able-bodied people, so that they create stigma and consequent psychological discomfort in highlighting the diversity. To satisfy users need related to kitchen environment accessibility, the spatial layout has been completely rethought, in order to create a new modular, flexible and adaptable concept of kitchen. This has led to the definition of a concept of cuisine that users can configure according to their needs.

Several solutions have been defined to improve physical accessibility of kitchen environment, and in particular, to address users’ needs due to mobility related impairment. The conceptual design started by the construction of the Hierarchical Task Diagrams.

As an example, Fig. 2 reports the polymorphic hierarchical task diagram describing the possible solutions to support the user goal “approach the countertop”. To this purpose, as can be observed, it has been assumed that the system should perform two polymorphic task: allow high regulation of furniture and provide free space of knees under the countertop. In particular, this last task can be performed by the user in two different ways (styles): by handling furniture or by extracting the countertop. In the same way, furniture handling can be performed in two different ways (manual or automatic), and so on.

As a second step, for every identified style, user activity are identified and User Activity Diagrams are built (Fig. 3). At the same time, the functions are identified that system must support to enable the user to achieve its objectives through the various

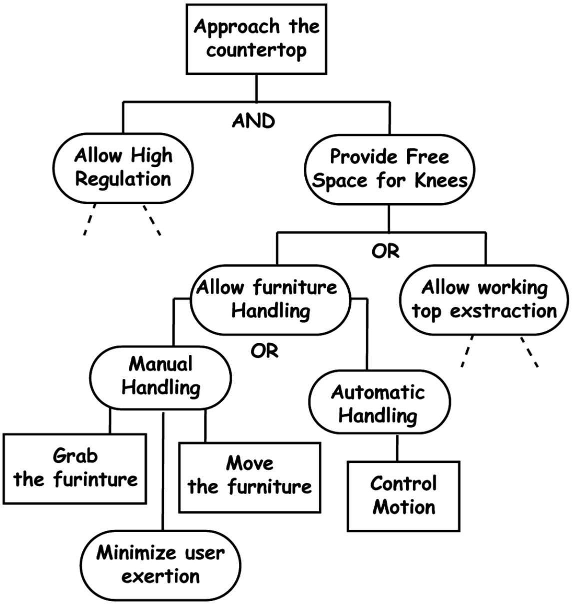


Fig. 2. Polymorphic hierarchical task diagram

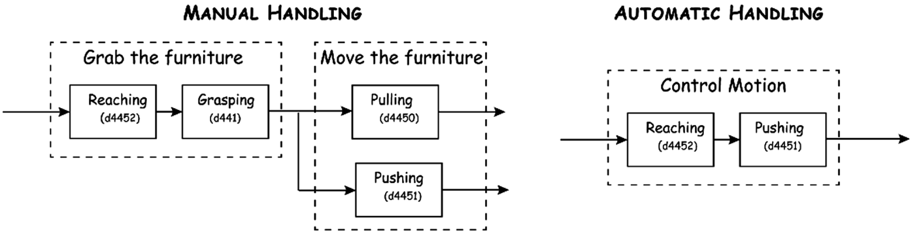


Fig. 3. Activity diagram related to user task necessary to "Allow furniture handling" in two different style (manual or automatic handling)

styles. In order to highlight those functions of a product in which the user is directly involved, action-function diagram is defined (Fig. 4).

Based on the systematic approach of Pahl and Beitz [17], several solutions for each product functions have been defined and assessed. The resulting overall solution is modular. Three new base cabinet typologies have been defined:

- Trolley cabinet (Fig. 5)
- Retractable storage cabinet
- Extractable storage cabinet (Fig. 6)
- Extractable and orientable storage cabinet (Fig. 7)

Each modules has been equipped with electromechanical systems that allow to move the base cabinets in order enable the access to the countertop to users in

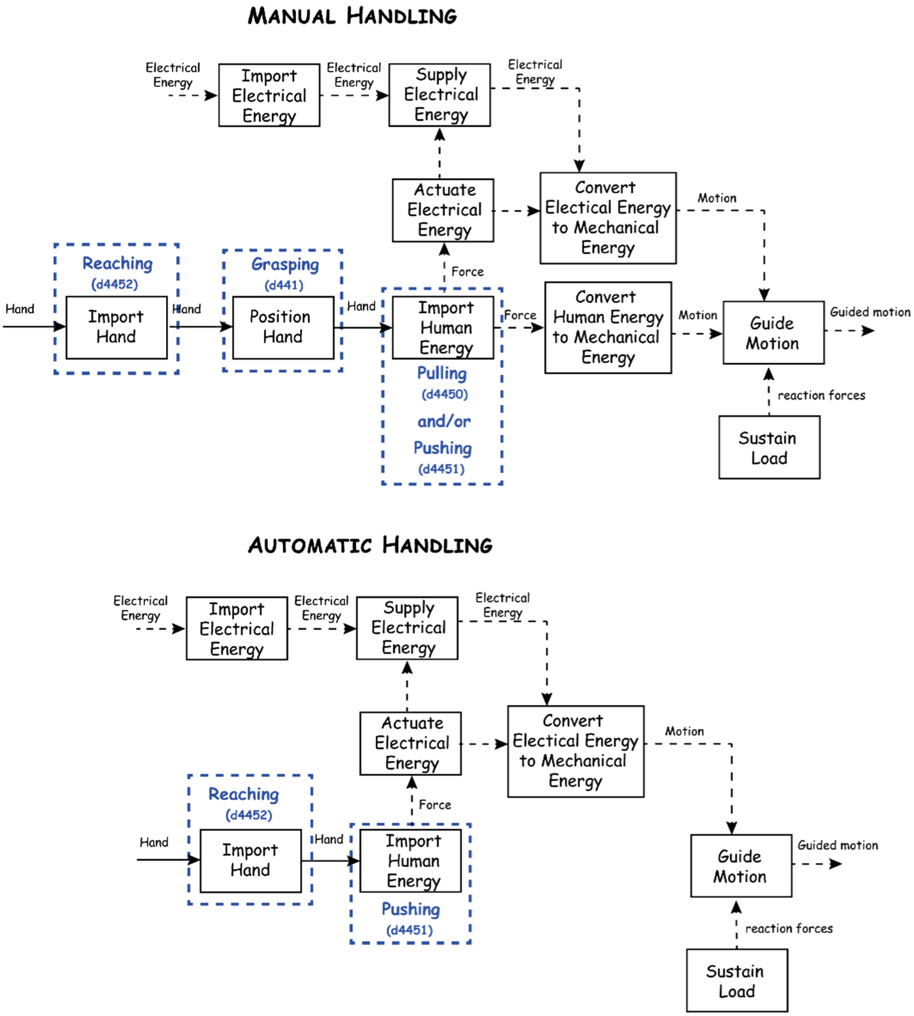


Fig. 4. Action-function diagram describing user-product interaction in performing "furniture handling" in two different style (manual or automatic handling)

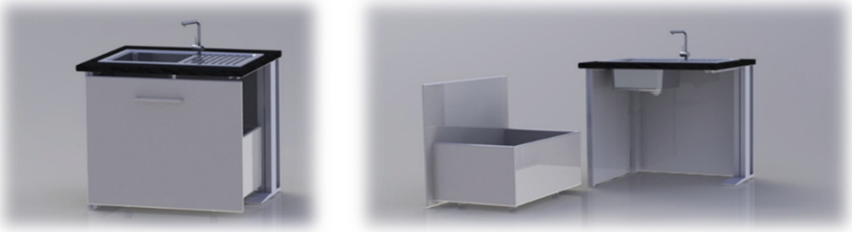


Fig. 5. The under-sink trolley cabinet

Fig. 6. The extractable cabinet

Fig. 7. The extractable and orientable cabinet

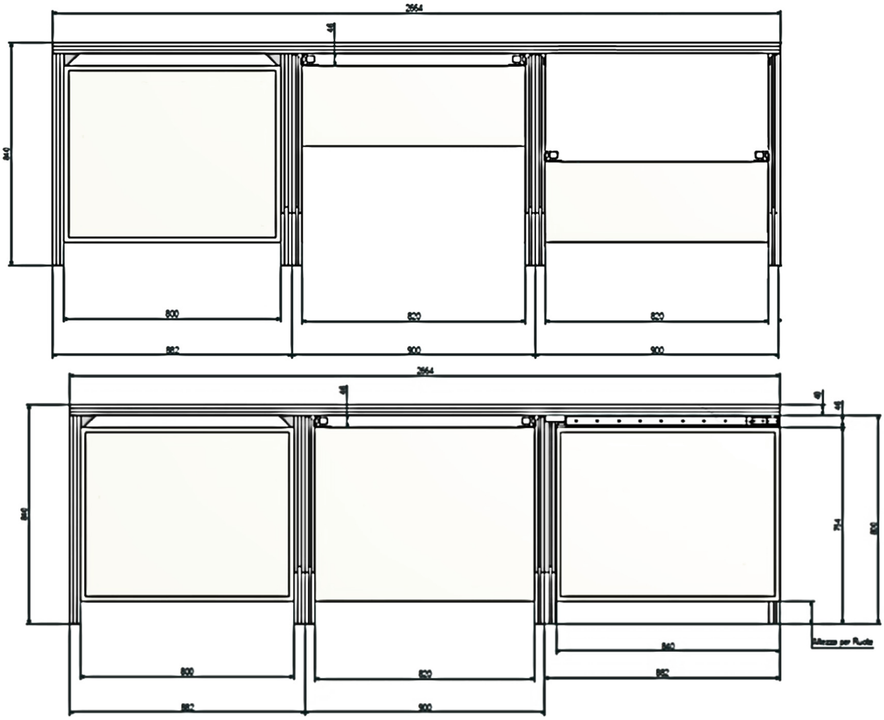


Fig. 8. The new structure applied to a trolley and two retractable base cabinet (on the top) and to a trolley, an extractable and an extractable and orientable cabinet (on the bottom)

wheelchair. The base cabinets have been designed to move independently of each other. In this way the kitchen can be opened completely or partially, moving only the necessary base cabinets without having to move all the modules.

The introduction of such modules required the fully redefinition of the kitchen furniture structure. In fact, normally the same base cabinets serve as structural elements for the countertop. This, from a conceptual point of view, has been made easier by the proposed approach, base on functional decomposition. The result is a new modular structure made by aluminum profiles (Fig. 8).

For each module, several width dimensions have been defined. For example the trolley cabinet can be 45, 60 or 90 cm width, while the other cabinets are available with a width equal to 45, 60, 90 or 120 cm. The depth of all module is equal to 60 cm, except for the retractable one that is 30 cm deep. The high of both modules and structure is adjustable from 80 to 90 cm.

Different combination of new base modules allow to design different kitchen layout, from the most traditional linear one to a completely innovative island configuration (Fig. 9). In this way, the user, at the time of purchase of the kitchen, can choose how to configure their environment according to their needs.

Fig. 9. Example of solution that allows people in wheelchair to access the countertop

The result, although fully accessible, is aesthetically pleasing, in line with current market trends that requires simple lines.

As also visible in the Fig. 9, the kitchen differs from all the other existing products of the same category because it is not “easily identifiable” as a “special” product: it looks like a traditional kitchen island and only through the movement of the base cabinets it can be “transformed” and becomes completely accessible even for wheelchair users.

5 Conclusion

A new approach to support conceptual design of inclusive product has been proposed, able to support the definitions of modular and adaptable solutions.

The proposed approach has been applied in the design of a new inclusive kitchen environment. The results product demonstrated the achievement of the following objectives:

- More storage space than the products of the same category: by comparing the new proposed solution with other similar product currently available on the market for elderly and disabled people, we can see that the new solution provide about twice the storing space than a typical kitchen model for disabled people. All available storing space is completely accessible for considered potential users.
- Adaptability to various levels of disability: the new proposed solution, thanks to its modularity, results easily adaptable in order to maximise usability and accessibility for different people.
- High aesthetic quality: the new solution present an aesthetic quality at least equivalent to standard kitchen currently available on market. The new model follows the current trend of the market which require linear and simple aesthetic design. The final quality of the product is high and in line respect to the company standard.

Future work will verify the effectiveness of the proposed method and tools in other design contexts.

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