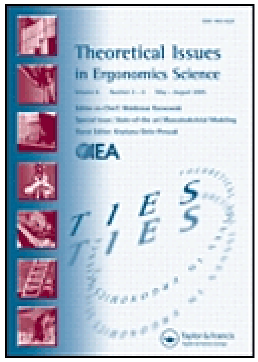

The Human Centric Lighting Approach for the Design of Age-Friendly Products

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As world's societal wellbeing is growing, in the near future the 'seniors condition' will force designers and companies to rethink the way they conceive, produce and sell products. This condition is fundamental for some strategic markets like the lighting domain. In this scenario, Human Centric Lighting (HCL) approach considers both seniors' biological aspects and technological advances to develop eco-efficient solutions that consider visual and non-visual aspects of light. This paper show the use of HCL as a new design approach able to help designers in the development of a wide range of lighting solutions; from the analysis of human conditions, this paper describes the research process used to design a HCL-Based System that perfectly meets seniors' needs.

Keywords: Human centric lighting; ergonomic design; new product development; old age, domestic lighting system

Relevance for Human Factors and Ergonomics

In the near future, the aging of the world population will influence Human Factors and Ergonomics (HF/E) studies. This paper introduces the Human Centric Lighting (HCL) as a new design approach useful to meet both biological aspects of seniors and technological advances related to the design of eco-efficient lighting solutions. This study is therefore in line with HF/E tradition, facing contemporary human's issues with traditional ergonomic studies and recent holistic design approaches, which are in line with the notions of Human Centred Design (HCD).

1. Lighting Design in Elderly Sectors: Between Human Wellbeing and Product Innovation

The relationship between light and human wellbeing has been widely documented in many studies (i.e. Veitch *et al.*, 1993; Veitch and Gifford, 1996; Wirz-Justice, 1996; van Bommel and van den Beld, 2004; Brainard and Provencio, 2008; Wirz-Justice and Fournier, 2010; Christoffersen, 2011; Pechacek *et al.*, 2013) and concerns medical, anthropological, social and psychological factors. But only recently the artificial light's comfort increased in importance for design and HF/E domains (i.e. Ticleanu *et al.*, 2015) supporting the people's interaction processes with products and environments.

Aging of people is highlighting new design challenges; new holistic and inclusive wellbeing-oriented design strategies are needed. Accordingly the rising class of *'seniors'* will be one of the most important categories of customers that will use domestic products (Moschis *et al.*, 1997), including lighting ones.

Human Centric Lighting (HCL) is a new design approach aimed to satisfy the psychophysiological and emotional needs of people (Srivastava, *et al.*, 2012). Seeing the seniors' condition, HCL approaches the study of artificial light aiming to improve the life of people in every aspect where light, as designable element, can be an essential factor. HCL considers both visual and non-visual effects of light that are less considered by design literature, producing higher controls on intrinsic lighting characteristics. HCL can be a useful approach to review seniors' psychophysical and social difficulties in an inclusive way, supporting the idea of seniors as a new group able to address the research and development of new highly-usable solutions for all.

2. Aims and Methodology

This work proposes a proactive convergence between the socio-psychophysical conditions of seniors with the new positive vision introduced by recent technological advances in lighting industry. It recognises the role of Design Research and Human Factors in connecting the social needs expressed by seniors (market demand), with the new enabling power offered by current industry advances (market offering). Accordingly, the HCL is a valid alternative to develop enabling age-friendly solutions, with the idea that products easily usable by seniors are also highly usable by youngers.

The aim of this work is to introduce the HCL as useful design approach usable to face the complex issues connected to the seniors' interaction with lighting products – i.e. dimensioning of elements, estimation of light flux, etc. – as well as to create ergonomically performing products that boost personal dignity and independence. This work is divided into two phases: analytical and design, described as follow:

- The analytical phase defines the scientific structure of this work; it aims to understand all biological, design and technical elements on seniors' condition.

- The design phase aims to develop a new HCL-oriented age-friendly lighting system for seniors. Notions belonging to Ergonomic Design, Engineering and Industrial Design domains are combined with HCL approach.

3. Seniors and Design Opportunities

The concept of old age has been repeatedly reviewed over years and, in principle, it is used to describe someone aged 65, or more, having some generic physical age-related difficulties like: physical disabilities, difficulties in interacting with technologies, etc. People live better and longer than past and, in the scenario of *'active aging',* seniors are active, both physically and professionally, playing active roles in the social, cultural and politic life.

In 2017 the world population reached 7.6 billion and over 13% are people aged 60, or more. UN's estimations expects that between 2017 and 2050, half of the world's population growth will occur in only nine countries, including: Nigeria, Democratic Republic of Congo, Pakistan, Ethiopia, Tanzania, United States of America, Uganda and Indonesia (UN, 2017). By 2050 the number of people aged 80 or more will triple (425 million); this number will be seven times higher by 2100 (909 million). Finally, the average age will continue to rise from 29.6 years in 2015 to 36.1 in 2050 (UN 2017).

From the design point of view, the previous data allow to anticipate what kind of actions companies should do in the near future to maintain their marker competitiveness and, then, what kind of strategies they could adopt in order to meet the seniors' needs. The simplistic design approach used till now must be re-discussed; traditional approach conceives *'exclusive'* – not inclusive – solutions that do not meet people's real needs, being out of markets demand and not in line with end-users' real psychophysical and social condition. Companies still have an idea of senior as *'weak old person'* needing of simplified, elementary or extremely easy-to-use solutions. On this human-centered design idea, Gretchen Anderson (2006) stated:

> Even as technology has gotten smaller, more powerful and cheaper, the design aesthetic for the pre-Boomer generation is still exemplified by orthopedic shoes. […] As our society matures, and Baby Boomers start swelling the ranks of the

> 'elderly', we will have to start coming up with better-looking, more useful products for seniors.
> […] Boomers will bring their great influence and purchasing power to bear on businesses and demand experiences that are more elegant and agile. […].
> We need exercise equipment for the mind and body, not just products that treat the inevitable decline. […] Our challenge is to make their lives meaningful.

The thesis expressed by Anderson follows, in some way, a part of the recent Design literature focused in the area of Universal Design and Inclusive Design (i.e. Seidel *et al.*, 2010; Mieczakowski and Clarkson, 2013); these works demonstrated that seniors have a own dignity, they want to be considered as active people and, mostly, they have quantifiable needs and wishes like younger demographic groups. If turned to the production domain, seniors expect to use *'inclusive solutions',* which are solutions suitable for all, not *'solutions designed for'* (Rossi and Barcarolo, 2019).

Although this social change is evolving the demand for new products, many companies do not recognize the value expressed by the senior class; at the moment, they only recognize that it will be essential to correctly intercept this issue in the future (Gassmann and Reepmeyer, 2011). Concentrating the strategic development of products only on young customers is wrong, as well as it is wrong to conceive and sell products that are exclusive for elders. In fact, seniors do not want to feel themselves belonging to a *'special category'*.

4. Synthetic Overview on Biological Factors of Lighting Stimuli and Seniors' Perception of Wellbeing

A fundamental factor connecting the human reactions to light stimuli is the circadian rhythm, which is defined in chronobiology as the *'internal clock of the human body'* (Lemmer, 2010). The circadian rhythm regulates physiological and behavioural rhythms like: sleep-wake cycle, vigilance, daily performance, hormone production, body temperature and metabolism. Environmental light is therefore the most powerful factor for its stabilization.

Light signals arrive at the brain following two ways: the first one is the optic nerve (POT), through signals coming from photoreceptors, and leads to the visual cortex and the retinohypothalamic tract; the second one is via the signals of the intrinsically photosensitive Retinal Ganglion Cells (ipRGC), which are a third family of photoreceptor cells leading the signals to the suprachiasmatic nucleus (SCN). SCN can be considered as the real internal clock of mammals and it is responsible for various physiological processes (Bernanrd *et al.*, 2007). In terms of production, four hormones are fundamental: melatonin, which regulates wakefulness (Hardeland *et al.*, 2006); cortisol, which influences the stress level (de Weerth *et al.*, 2003); dopamine, which regulates human's pleasure, vigilance and muscle coordination (Hirsh *et al.*, 2010); serotonin, which regulates, for example, the need of carbohydrates (Pontes *et al.*, 2010).

Studies have also confirmed that both illumination and duration of light exposure are relevant for the circadian rhythm (Warman *et al.*, 2003). Assuming long exposures, domestic lights can condition people's circadian rhythm. Consequently, night light exposure could negatively affect on the production of melatonin.

The perception of light influences the life of people; it stimulates their awareness on the time of day and, mostly, on how much energy they should have in that exact moment (energy need – i.e. hunger). In 2012, the American Medical Association (AMA) documented the need to develop modern technologies to minimise the interruption of circadian rhythm (Blask *et al.*, 2012).

A recent study (Scheuermaier *et al.*, 2011) has shown that seniors spend roughly 38% of their waking hours in moderate room light intensity (<100 lux) and more than the 15% with brighter light levels (≥ 1000 lux), which is equivalent to sunlight. Accordingly, traditional artificial lights are inadequate for seniors' specific needs. Moreover, for elderly people, the ability to focus objects tends to decrease, as well as the ability to compensate the lower levels of brightness and the detection of colours. Diffused light acts on the chromatic perception reducing the differences of colours at the edges of silhouettes. Thus, to have an appropriate visual acuity, a person aged 60, or more, needs of a 2-5 time higher level of light than a person aged 20 (van de Kraats and van Norren, 2007).

Circadian rhythm is also influenced by the quantity, the time, the duration of light exposure and its spectrum. In elderly people, high levels of natural light increase the level of melatonin.

Finally, ageing implies eyes-related diseases and disorders, such as loss of vision and blindness. In particular, loss of vision is the intermediate condition between normal vision (20/20) and blindness (3/60) (WHO, 2011).

5. The Human Centric Lighting Approach: Definition, Design Opportunities and Potential Limitations

A 2013 joint study of LightingEurope and the German Electrical and Electronic Manufacturers' Association (ZVEI) promoted the Human Centric Lighting (HCL) as a design-oriented approach useful to improve the human wellbeing, people's concentration, safety and efficiency in workplaces (Kearney, 2013). This study affirms that HCL can support healing processes and prevention of chronic diseases among persons with irregular daily routines or in elderly care. As reported by Heller (2016), HCL centers on the relationship between light and levels of wellbeing, where the effects on circadian rhythms can be correlated to specific light conditions.

Compared to traditional design approach, HCL considers both visual and non-visual effects of light – i.e. biological and emotive factors – rarely taken into account; this allows to have a quasi-total control on lighting sources, including: direction, intensity, chromatic gradients and exposure time. Therefore, HCL is not a product-centered design approach; it holistically considers people in their environments, taking into account their activities, tasks, wishes and human conditions, to generate smart solutions that meet human's physiological aspects and new technological advances.

Even though HCL is still less used in Design discipline, it offers a large number of benefits. A recent study (de Kluizenaar *et al.*, 2016) has shown strengths and main difficulties for the development and the diffusion of HCL; study's results are synthetically discussed below.

A first chance concerns the creation of customized systems of smart lighting solutions. Stakeholders have expressed the desire to have functional solutions, but also upgradable and implementable over time. This factor could improve, for example, the 'smart applications' sector (i.e. using Bluetooth and Wi-Fi, lighting systems can be controlled via smartphones and home automation systems) and, then, the sector of green buildings using systems for energy efficiency that mitigate the economic and environmental impacts.

A second promising chance concerns the development of biologically effective lighting solutions for human health and wellbeing. HCL could improve the wellbeing of patients in hospitals, humanizing the quality of sleep and preventing chronic diseases. For this reason, the personal care sector could probably be the most promising field of application for short-term experimentations. Personal care sector can best benefit from wellbeing-oriented lighting solutions aimed to support the active aging.

The extension of the HCL into work environments – i.e. offices, schools, etc. – introduces a third chance, which concerns biologically effective lighting solutions for improving cognitive performances. In these contexts, full control of light can improve people's mood, satisfaction and productivity. For example, in schools light plays an important pedagogical role; it increases concentration and reduces errors.

Finally, light plays a strategic role in the creation of aesthetically pleasing and suggestive environments (i.e. architectural lighting). This fourth chance concerns the design and the development of pleasant spaces; for example: rooms with comfortable lights increase productivity; pleasant classrooms increase students' performance, etc.

On the other hand, the study conducted by de Kluizenaar *et al.* (2016) identified four main limitations related to the diffusion of HCL, which mainly concern: the lack of information and lack of awareness in the lighting industry, the lack of precise and quantified economic returns in the use of HCL-based products, the lack of standards and rules to support the technological spreading, and finally the lack of market insights, guidelines and evidences on the technological pros.

6. Design and Development of an Age-Friendly Lighting System

The design process used to develop a HCL-oriented age-friendly lighting system followed four different phases; moving from the analysis of end-users' abilities and needs, useful to know all user-centered aspects, to the design and implementation (i.e. ISO, 2010). The solution here presented, and referred to an academic trial, has been also verified using specific HF/E tests (anthropometric measurements and Universal Design checklist) in order to have the best solution possible (Deli, 2018).

6.1. Analysis of Seniors' Abilities and Design Correlations

The analysis of seniors' psychophysical conditions allowed to define a descriptive framework connecting human conditions with design implications and senior-centred needs. Such conditions (Table 1) have been used to describe the quality of seniors' interaction with products, in order to understand their needs and, from the design point of view, the nature of design requirements to be developed. The framework has been therefore developed using existing literature, standardization references (Denno *et al.*, 1992; ISO, 2001; Farage *et al.*, 2012) and participative research sessions with a sample of 12 potential stakeholders (co-design on lighting domain). Stakeholders' data have been later summarized and screened to detect harmonized needs for lighting domain.

Table 1 about here.

6.2. Analysis of End-Users' Needs and Development of Product's Design Requirements

From the previous analysis, and from the review of potential design implications related to their conditions, a meta-projectual analysis has been developed to connect the medical domain with the design one. Specifically, the *'Effects/Implication of Age'* shown in Table 1 has been used to understand the end-users' needs and to develop a new class of design information (Table 2), composed by: *'Classes of Design Requirements'* (left column) and *'Detailed HCL-Oriented Design Requirements and Recommendations for Lighting Companies/Designers'* (right column). This analysis allowed to have a clear and detailed framework of design information useful to develop, in the next design phases, the design concept and the HCL-oriented design solutions. *'Recommendations for Lighting Companies/Designers'* have been developed to be as scalable data for industry-related developments. Moreover, in this phase, relevant data belonging to Universal Design (Connell *et al.*, 1997) and Design for Sustainability (Manzini and Vezzoli, 1998) domains have been used to have accurate information about end-users.

Table 2 about here.

6.3. Development of the HCL-Based System

The development of the HCL-Based System started considering the seniors' fundamental needs and, then, how to apply the list of *'Detaild HCL-Oriented Design*

Requirements'. In this early design phase, the attention was addressed to the development of a set of basic elements to be refined later. This process has defined the five main elements of the lighting system: a base, a spotlight, a light diffusor, a lighting system and a set of controls (Deli, 2018).

As shown in Figures 1 and 2, the HCL-Based System is composed by only four main elements: a reflective surface, a base, a rod and, finally, a lighting source linked to the rod. The reflective surface is a 13 mm thick composite sandwich composed by: painted anodized aluminium, PMMA (Polymethyl methacrylate) and aluminium framed MCPET (highly reflective PET foamed sheet). The base is made in black-painted anodized aluminium and contains an integrate solution to connect the rod and all electrical components like: power transformer, COB (Chip on Board used for the dynamic regulation of LEDs) ventilation slots, etc. The rod, made in black-painted anodized aluminium, is 25 mm diameter and contains two light sources: the first one is a vertical 750 mm light diffusor and the second one is a 90 mm horizontal light diffusor. All controls can be regulated in height – between 950 e 1110 mm – to meet all anthropometric conditions, and in depth – 350 mm – using an electric rail. The overall height – 1800 mm – has been chosen both to meet all anthropometric conditions and to create an elegant solution for any domestic environment. In general, the idea was to create a low thickness senior-friendly solution.

Figure 1 about here.

Figure 2 about here.

6.4. Anthropometric Measurements and Age-Friendly Design Constrains

The early concept design has been verified for anthropometry standards using one of the most used reference for Industrial Design discipline (Pheasant, 1996), which has allowed to perfect the dimensions of all components with which seniors will directly interact (i.e. knobs, connectors, etc.) (Figure 3). In terms of anthropometric verification, the populations – percentile (%ile) – used as for references were:

- 99 %ile American elderly men aged 65 to 79, used for the product's sizing (min. size).

- 1 %ile American elderly women aged 65 to 79, used for the product's sizing (max. size).
- 99 %ile American elderly men aged 65 to 79 and 1 %ile American elderly women aged 65 to 79 used for the control sizing (max. and min. size).
- 99 %ile American elderly men aged 65 to 79 and 1 %ile American elderly women aged 65 to 79 used for the sizing of all surfaces, lighting systems and handling objects (i.e. knobs, connectors, rods, etc.) (max. and min. size).

Figure 3 about here.

Later, the measurements refined through anthropometric tests have been combined with the original lighting system to obtain a coherent solution that meet both human insights (i.e. HCD) and technological components (technology-push approach). As last verification, we used the Universal Design checklist (CUD NCSU, 2002) to validate the HCL-Based System even with critical end-users' conditions. This confirmed the coherence of the solution even for the Universal Design principles.

6.5. Technological Implementation and Full Simulations

In the last design phase, some simulations have been developed to tests the different lighting qualities and conditions of use of the HCL-Based System. Such simulations were addressed to understand the visual pleasantness of lighting sources in all potential domestic uses. The aim of this phase was to verify the lighting effects with the HCL approach in order to confirm the design approach used or, at least, to implement specific elements if needed. From the technological implementation of all system's elements, some provisional conditions – scenarios of use – have been created to show the qualitative and quantitative performance of all lighting sources. In particular four main simulations have been developed for:

- Standby/Activation lights: an integrated twilight sensor detects the amount of light and, when needed, automatically activates the product – it reveals the presence of the lighting system through the activation of the controls on the PMMA shell.

- Side light (5 lm ca.): it provides night lighting in case end-users need to move in the dark. The lighting system illuminates the floor – and adjacent furniture – to show the safest way or the nearest switch, reducing the risk of falls.
- Diffused light sources: spotlights vary from 800 lm to 1600 lm. The colour temperature used is D65 – daylight 6500 – equivalent to a solar light simulation of 6500 °K. The controls contained in the lighting system allow to vary the colour temperature from 4000 °K to 2700 °K.
- Direct light sources: from 400 lm to 600 lm.

Some full simulations have been used to set the overall product's aesthetics, as well as to have early feedbacks from potential customers in relation to potential domestic contexts of use (Figure 4).

Figure 4 about here.

7. Conclusions and Discussion

Ageing of world population is producing remarkable effects in the design and development of personal products; as reported by many studies, it is currently forcing designers and companies to rethink and approach the social issues with new tools and design approaches. As the need of lighting solutions is a basic factor for the everyday life of people, the *'seniors condition'* is producing a new approach to market with new and proactive solutions based on inclusive-oriented approach.

HCL is a fast-growing approach that considers both visual and non-visual aspects of light, allowing to conceive new products able to meet all psychophysiological conditions of all end-users. Compared to the seniors' condition, HCL can play a crucial role in the design and in the selling of smart human-centred products.

This paper has shown that the HCL approach can be used in the design of highly usable and eco-efficient domestic lighting solutions that meet the seniors' needs and abilities. As it has been discussed in the first part of this paper, the seniors' psychophysiological conditions are strongly influenced by light condition, involving visual, non-visual, ergonomic and design aspects. So, the research here presented demonstrates that the development of lighting solution for people aged 65, or more, is a complex issue, but the use of recent design approaches, the investigation of current advances in medical and technological fields, and the use of the HCL approach can help all designers in the design of elegant eco-efficient and effective age-friendly solutions able to meet both human needs and industrial production.

Finally, evidences have shown that HCL can be considered in line with traditional aims of HF/E discipline, while it has been possible to use and adapt traditional tests and design approaches with new socio-demographic issues.

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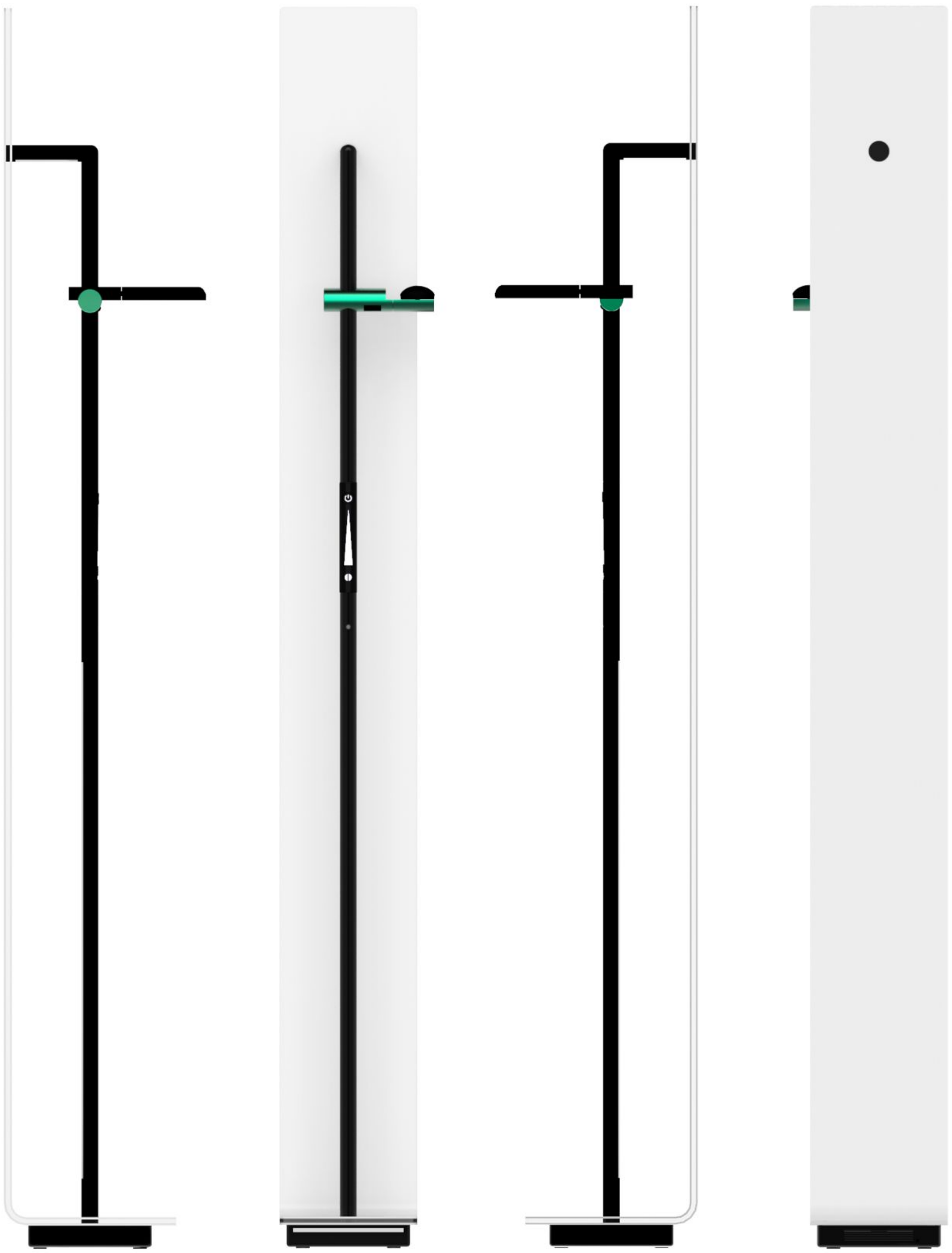

Figure 1. HCL-Based System: Four views.

Figure 2. HCL-Based System: Movements of the lighting source.

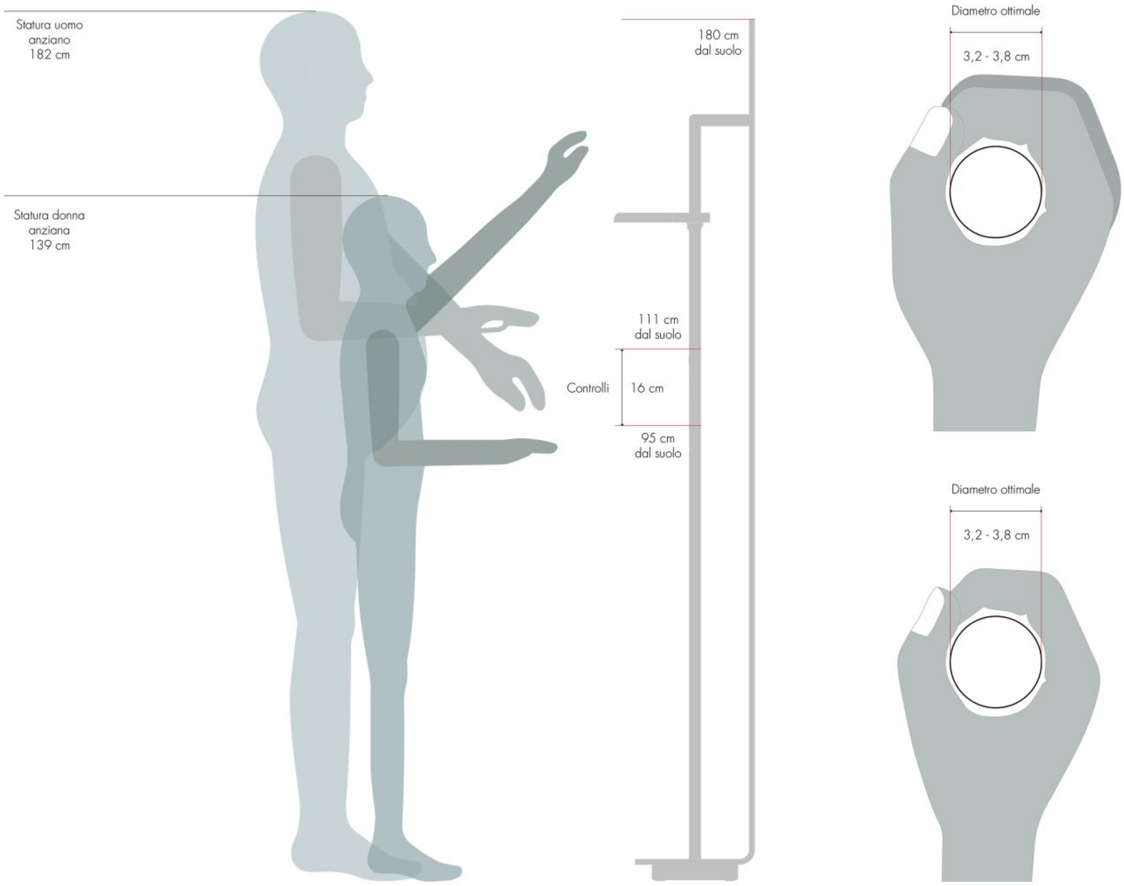

Figure 3. HCL-Based System: Anthropometric tests.

Figure 4. HCL-Based System: Full simulations in domestic contexts of use.

Table 1. Analysis of seniors' abilities.

Skills	Literature-based UCD Analysis		Harmonized Senior-Centred Needs (Co-Design Research) – *Need of:*
	Effects of Age	**Risks and Design Implications**	
Eyesight (Sensorial Skills)	Changes in the physical structure of eyes affect visual functions, for example: • Loss of visual acuity. • Loss of vision at short/long distance. • Reduced field of view. • Colours perception. • Depth of view perception. • Speed of adaptation to different levels of lights. • Sensibility to light (Pirkl, 1994). • Reduction of peripheral vision (Collins *et al.*, 1989).	People are more exposed to risks, such as: • Low recognition of sharped elements to grab. • Low perception of unstable objects. • Low recognition of discontinued surfaces and obstacles. • Low recognition of flames and hot surfaces. • Low recognition of corrosive elements (unless evidenced). • Low recognition of chromatic stimuli.	• Have a semantic concentration of functions. • Visual reduction in the number of controllers, and their need. • A decreasing in the visual efforts. • Use of solutions having qualitative and quantitative 'semantic coherence'. • Use 'visually characterized' elements.
Hearing (Sensorial Skills)	Decreased perception of pure tones and low sounds (circa –2,5 dB each ten years up to the age of 55; circa –	People could not be able to hear emergency sounds, including high frequency tones.	• Have combined communications (i.e. acoustic+visual). • Differentiate

	8,5 dB each ten years after the age of 55 (Davis *et al.*, 1990)).		artificial stimuli (i.e. regular warnings) from natural ones (random sounds).
Touch (Sensorial Skills)	Seniors have lower tactile sensitivity, so they are more sensible to cold temperature and have a slower reaction to high temperatures. The haptic perception, the reaction on pressures and the responses on vibrations decrease (Hilz *et al.*, 1999).	Seniors having haptic hypersensitivity could get hurt; such stimuli can get can hurt people with reduced haptic sensitivity, if exposed to long haptic stimulation. Some conditions decrease the ability in grabbing and handling.	• Have 'confortable' surfaces to grab/handle (i.e. soft, textured, etc.). • Limit the time of physical efforts. • Limit the need to move objects. • Have 'enabling' surfaces.
Taste and Smell (Sensorial Skills)	In principle, the ability to recognise smells decreases with age.	Taste and smell losses affect, for example, the detection of toxic materials and smells from electrical malfunctions.	• N/A*.
Balance (Sensorial Skills)	Attention deficits and sight limitations reduce the ability to prevent hazards and to react in case of instability. The muscular weakness contributes to the loss of equilibrium. People with vestibular and/or	Discontinued surfaces, obstacles and protrusions can generate falls; seniors are more exposed to domestic fall down. Equilibrium issues increase the fear to fall down and affect the personal	• Have time to move from point A to point B., even using 'enabling' surfaces and/or solutions to walk. • Use surfaces and paths that minimize the physical efforts. • Use paths that are

	with proprioception problems are used to compensate these conditions with sight.	independence.	confortable from the synesthetic point of view. • Safety, dignity and autonomy during movements.
Dexterity (Physical Skills)	The inability to conjoin thumbs and other fingers together, or move them away. Complex tasks like push-on and rotate may be painful, or impossible. Seniors suffering by involuntary muscle spasms can have problems in the pursuing of precision tasks.	This condition influences the dimension, the shape and the position of commands. People with lower dexterity can hurt themselves or they could accidentally activate commands.	• Use of 'enabling' controllers that support imprecise activities. • Have an improved relation between: a) dimension of controllers and b) time needed for their use. *Dexterity is relevant for seniors, while stakeholders have reported that generally it is not a serious issue.*
Handling (Physical Skills)	Handling may be affected by the inability to simultaneously use both hands, or they have to be moved in confined spaces. A lower level of manipulations generates slower times	People with reduced handling ability can have accidents (i.e. unboxing, fixing, etc.). The solutions should minimize such risks and prevent wrong actions.	• Use of 'enabling' controllers that support imprecise activities. • Have an improved relation between: a) dimension of controllers and b) time needed for their use.

	of reactions and risks.		• Have 'confortable' surfaces to grab/handle (i.e. soft, textured, etc.). • Limit the time of physical efforts. • Limit the need to move objects. • Have 'enabling' surfaces. • Perform tasks that improve the human coordination. • Perform tasks minimize the errors, and their effects.
Movement (Physical Skills)	Movement limitations affect the daily activities, for example: • Inability to move masses on legs. • Reduced speed of walk and stride. • Lower range of knuckle movements. • Inability to perform coordinated movements.	Seniors having physical problems are more exposed to properly act in critical, emergency or unexpected situations.	• N/A*. *Movement is relevant for seniors, while stakeholders have reported that generally it is not a serious issue since they perform the actions according to their confidence in doing movements.*
Power and Resistance (Physical Skills)	Limitations of muscle force generate physical fatigue during the extended use of	Limitation of all activities where the physical strengths is needed, including the	• N/A*.

	products. The control of passive movements (i.e. gravity-related actions) is affected.	light handling for long time.	
Intellect (Cognitive Skills)	Seniors can have difficulties to focus, perform specific tasks and move the attention on various tasks. Disorders of the circadian rhythm make people less vigilant.	Several problems related to: • Comprehension of products. • Understanding of tasks. • Feedbacks recognition. • Understanding of functioning. • Perception of product's effected on personal level of wellbeing.	• Use of rhetorical elements to recall functions and understandable step-by-step functions. • Have hierarchical functional categories. • Use of comprehensive semantics to support the tasks' recognition. • Have 'enabling' feedbacks. • Have multiple choice to recall/understand tasks.
Memory (Cognitive Skills)	Lower cognitive skills can generate mental confusions. This condition affects both Short- and Long-Term Memories.	Problems related to memory can generate severe risks when tasks to be performed are incomplete or when there is a dangerous situation. The solution must always guarantee a	• Use of rhetorical elements to recall functions and understandable step-by-step functions. • Have hierarchical functional categories.

		safe and error-friendly use.	• Use of comprehensive semantics to support the tasks' recognition. • Have multiple choice to recall/understand tasks.
Language and Literacy Rate (Cognitive Skills)	Aging and speech are directly connected; seniors show difficulties in communicate what they think.	People having difficulty in linguistic expressions are more exposed to risks, if unable to understand relevant instructions of alert signals.	• Have/use visually enhanced controls. • Clearly understand complex functions in relations to tasks to be performed. • Know the utility of unusual commands, and their benefits.
* N/A is used to show contradictory, inconsistent and generalist data, when the sample of stakeholders was not able to provide meaningful insights to be harmonized.			

Table 2. Design requirements and related detailed HCL-oriented design requirements.

Groups of Design Requirements and their Definitions	**Detailed HCL-Oriented Design Requirements and Recommendations for Lighting Companies / Lighting Designers**

Aesthetical/Morphological Design Requirements (Distinctive Shapes and Affordance)
 	
Def.: *Make easy the formal and the functional comprehension of the product and all its parts.*
	• Distinctive shapes allow to recognise the product, its parts and the functioning (self-explanation of use), for example:
	  ○ Distinctive shapes help the recognition of product's parts and, indirectly, their functions.
	  ○ Distinctive shapes increase the level of security preventing misuses.
	  ○ Distinctive shapes support the maintenance processes and the overall product's functioning.
	  ○ Distinctive shapes have to be coherent with semantic properties (i.e. visual dimensions and weight).
	• If composed by complex structures, or families of elements, the overall shape must be self-explicative.
	  ○ Self-explicative shapes improve the processes of autonomous assembling, even by non-trained people.
	  ○ Self-explicative shapes support the recognisability of parts in relation to their functions.
	  ○ To strengthen communicative messages, self-explicative shapes can work in combination with synesthetic media (i.e. visive+sound effects, visive+haptic effects, visive+mass effects, etc.)
	• The product must not appear like *'designed for seniors'* (prevention of social stigmas and coherence with all markets); as a general rule:
	  ○ Products *'designed for'* have a low market impact.
	  ○ Products *'designed for'* generate inhibition in their use, even if their use is fundamental for everyday

	life. ○ Products *'designed for'* have a lower affordance and generates a poor user engagement.
Aesthetical/Morphological Design Requirements (Colours and Contrasts) Def.: *Make easy the chromatic recognition and the psycho-perceptive comfort.*	• Avoid disadvantageous use and combinations of colours (i.e. Hornor, 2013), for example: ○ Blue-purple combination. ○ Green-brown combination. ○ Green-yellow combination. ○ Green, yellow or purple on a green background. ○ Light colours on a white background. ○ Coloured/textured background with coloured text. ○ Red, blue, or purple on black background. ○ White gradient with white text. ○ Yellow, blue, and magenta on red background. ○ Bright blue or pale yellow background. • Improve contrasts of colours, for example: ○ Use grey with fuchsia, red, violet, pink and blue. ○ Use beige with blue, brown, emerald, black, red and white. ○ Use white with everything, especially blue, red and black. • Provide information using other senses, and their combination. ○ Balance the quality and the quantity of synesthetic communications in order to prevent cognitive overloads. ○ Hierarchical communication are strongly preferred and, in general, they have to be based on this communicative path: ▪ Visual communications are preferred for first insights and immediate system's reactions. ▪ Hearing stimuli and/or vibrations can be

	▪ used to give consistency to visual messages (i.e. feedbacks). ▪ Complementary stimuli can be used to give completeness to previous stimuli. ▪ Olfactory stimuli can be used pay a strong attention to the system's coherence, in order to prevent misunderstandings and warnings. • Prefer short wavelengths colours: ○ Prefer colour range from violet (~ 450–400 nm) to cyan (~ 520–490 nm). ○ In general, prefer blue-related colour tones. • Foreground elements must be clearly perceptible from background.
Technological Design Requirements (Dimension and Weight) Def.: *Product's lightness and physical compactness. Materials suitable for all uses.*	• Product's dimension and weight must allow the handling, reducing the physical effort needed, for example: ○ Product's dimension has to be consistent with the lighting functioning (i.e. actuation, transportation, moving, maintenance, etc.). ○ Product's dimension has to be consistent with the effects generated by the lighting source. ○ Product's dimension has to be coherent with the 'no-redundancy' design criterion. ○ Product's weight has to be coherent with the *'movability'* criterion (i.e. the more the product needs to be moved, the less it must weight). ○ Product's actuation has to be physically calibrated to seniors' physical capability. • The product must be compact. ○ As a general rule, compact products are perceived as more user-friendly than large products; especially for seniors, this design requirement is important to establish first insights for *'autonomy of use'* and *'usability'*.

	○ Similar to *'Aesthetical/Morphological Design Requirements'*. • The product must be composed by easy-to-use components. • Prefer safe and wear-resistant materials. ○ According to the technological capability of lighting companies/designers, this design requirement implies to pay more attention on the technological quality of the product, which will generate a more competitive ROI.
Technological Design Requirements (Materials and Surface Finishes) Def.: *Choice of safe surfaces, differentiated according to the use and the tactile perception.*	• Prefer antiskid surfaces to give a more efficient handling/grip. ○ The 'antiskid quality' can be generated/improved using many design strategies, including: ▪ Concentration of textured elements. ▪ Rationalization of masses. ▪ Rationalised shapes and smooth connections. ▪ Use of layered parts using materials that improve the grip. • Differentiate surfaces' textures to improve the identification of parts and controls, for example: ○ Use colours – if/when possible – as communicative solution to provide immediate information on parts, functions and control elements. ○ Use concentration/differentiation of textures and masses to support direct/indirect communications. ○ Provide discontinuity in surfaces' texture in order to provide semantic and haptic feedbacks. • Lighting surfaces should be opaque or translucent. • Carefully consider the haptic feelings caused by the use of different materials, and their combinations (i.e. wood-metal).

	○ Haptic feeling is a powerful communicative element that can be used to support explicit/implicit messages (i.e. hard, soft, hot, cold, regular, discontinue, large, big, etc.).
Functional Design Requirements (Alternative Shapes) Def.: *Possibility to differentiate the informative and functional product's outputs.*	• Provide a clear representation of the product (self-explanation and presentation) to allow the understanding of functions and the sensorial abilities needed. ○ Similar to what has been described for 'Aesthetical/Morphological Design Requirements'. • Provide coherent informative inputs on the accessibility of components (useful for people with disabilities). ○ Inputs have to be consistent, however: ▪ Avoid redundant informative inputs. ▪ Avoid random informative inputs (develop and support coherent messages). ▪ Balance time and intensity of informative inputs.
Functional Design Requirements (Logical Processes) Def.: *Simplicity of uses, processes and feedbacks.*	• Improve end-users' problem-solving skills (useful for people with disabilities) (i.e. set the design on end-users' real abilities, develop the design of the lighting solution involving stakeholders in the design process, use co-design approach, etc.). • Provide feedbacks (output) after all correct actions (input). • Promote the self-learning of tasks to be performed (i.e. learning-by-doing). ○ Self-learning can be improved using semantic and cognitive 'rewards' that produce engagement and happiness. ○ Self-learning of tasks can be easily supported developing expectation-based routines (improvement of cause-effect process). ○ Self-learning has not to be redundant, or perceived

	as such.
Functional Design Requirement (Multitasking) Def.: *Minimum cognitive efforts needed focused on functioning of product.*	• Avoid and prevent multitasking activities. In general multitasking is not a bad design strategy; however the senior condition imposes to reflect on the density of multitasking activities to be performed by end-users (amount of tasks per time needed for their fulfilment).
Usability-related Design Requirements (Effectiveness) Def.: *Make easy the grab, the handling and the control of the product.*	• Develop coherent shapes to make easier the handling, for example: ○ Increase the prehensility of product and product parts in order to give autonomy and satisfaction during the use. ○ Concentrate weights and masses in order to balance the stability of the product, as well as its morphological coherence. • Controls should allow a comfortable grip, avoiding the torsions of wrists, for example: ○ Levers and buttons are preferred. ○ Textured surfaces are preferred to increase the grip and help to modulate the force needed. ○ Controls should be distant to avoid mutual interference and their actuation must be revealed by multisensory feedbacks. • The solution must prevent the repetition of unnecessary tasks.
Usability-related Design Requirements (Efficiency) Def.: *Make easy the use of unmovable and*	• Make the product usable, movable and manageable even by people with physical impairments. • Create recognizable and accessible controls. ○ Controls must be easy-to-grab, flexible, adaptable and usable with one hand. ○ Where possible, organise all controls in thematic

cinematic parts (and their caught).	groups.
Perception-related Design Requirements (Illumination) Def.: *Give the chance to have normal and/or optimal light condition in any circumstance, and for all activities. Use of correct surfaces for direct/indirect lights.*	• Lights have to highlight relevant details to reveal potential obstacles/barriers. ○ If needed, lights can be used to highlight obstacles and that could affect the human safety, as well as the overall functioning stability. ○ Lights can be used as indirect elements to support and strengthen the 'safety level' in any operational context. • Instructions and controls have to be always readable. • Balance the lighting effects and avoid the use of reflective surfaces in order to prevent glares and sharp shadows, for example: ○ Prefer distributed low intensity light sources. ○ Prevent sudden changes in light levels, to give eyes the right time of adaption.
Perception-related Design Requirements (Temperature) Def.: *Protection from excessively hot or cold components.*	• All touchable surfaces must not be too hot or too cold. • Use high thermal dissipation materials. • Make evident the parts where temperature is hot or cold. • Too hot or too cold surfaces must not be reachable by hands and body parts, neither accidentally.
Perception-related Design Requirements (Sounds) Def.: *Use of proper sounds to guarantee comfortable acoustic levels.*	• Sounds have to be clearly perceived and ambient noise must be reduced (frequencies between 500 Hz and 2000 Hz are preferred). ○ When needed/possible, the use $\geq$60 dB sounds is highly preferred. ○ Avoid unexpected and high frequencies. • Each action must be linked to an acoustic feedback in order to give semantic consistency to any action, both positive (expected feedback) and negative (unwanted).

	• Where possible, integration with multisensory stimuli (i.e. vibrations) is preferred.
Safety-related Design Requirement (Stability) Def.: *Integrity and safety in the assembly of products.*	• The product must have a mechanical and electrical stability during the use.
Safety-related Design Requirement (Assembly/Wrong Use) Def.: *Protection against failures.*	• The product should be always restored in its original condition, even when it is improperly used/assembled. ○ Provide alternatives in the use and clear restore processes that can be used to reset the overall lighting system. ○ Use of semantic functions in order to support the return to previous functioning status (i.e. use of morphological incompatibilities, use of aesthetical incompatibilities, etc.).
Safety-related Design Requirements (Packaging) Def.: *Make easy the understanding of packaging. Choice of proper materials.*	• The packaging should use forms, dimensions and materials coherent to allow the easy opening and the fast closing. ○ Avoid sharp edges and surfaces. ○ Limit the number of containers. ○ Make clear the identification of product's parts and components, especially if the lighting solution has to be assembled by customers. ○ Use different materials that support the products' characteristics (i.e. shockproof containers for fragile components). ○ Avoid packaging having reflective surfaces. • Reduce the physical efforts needed to open packaging (i.e. pop-up boxes are preferred).
Design Requirements for Maintenance (Ordinary	• Design and use of standardized and interchangeable elements, for example:

and Extraordinary) Def.: *Make easy the maintenance of products (i.e. cleaning, assembly, reparability, etc.).*	○ Facilitate the access to all parts; prevent the use of holes and discontinuous surfaces (i.e. accumulation of dirt). ○ Improve the substitution of elements. ○ Make easier the ordinary maintenance. • Allow the daily/ordinary maintenance. ○ Use consistent and consolidated design guidelines for lighting domain to support the processes for daily/ordinary maintenance.
Environmental Design Requirements (Resurces and (Dis-)Assembly) Def.: *Minimization of the resources needed to produce the solution. Use of a limited number of parts. Use of eco-efficient and eco-compatible materials. Promotion of disassembly and recycling of components.*	• Use Life Cycle Design strategies and Design for Sustainability insights to support the rationalization of resources and (dis-)assembly (i.e. Vezzoli and Manzini, 2008), for example: ○ Use only the strictly necessary amount of material. ○ Avoid the use of oversized elements. ○ Prefer certified materials and manufacturing processes. ○ Where possible, integrate functions and minimize the number of elements. ○ Select homogeneous materials (monomateric approach) obtained from coherent manufacturing processes. ○ Make easier the disassembly of all elements and their disposal. ○ Avoid unnecessary finishing.