SPECIAL ISSUE ON FOOD COLOUR

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SOMMARIO | SUMMARY

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Special Issue on Food Colour

Editorial

2015 was a very important year for food culture because in Milan took place the Universal Exposition Expo 2015. Expo 2015 was held under the theme *Feeding the Planet, Energy for Life*. It was very natural, for an international journal based in Italy to dedicate a special issue to the relationship between food and colour.

As editors of this special issue, we took into consideration the statement of the famous gastronome Savarin: *"Tell me what you eat, and I'll tell you who you are"*, since the many color hues related to food are indeed an expression of culture, in addition to being nutritional and health aspects.

We could imagine that food is a huge topic, and obviously we know very well that colour is also an interdisciplinary topic. What we could not forecast is the incredible extent of the subjects belonging to the overlap between food and colour. In this special issue, only to give same examples, you can find papers about tea, packaging, lighting, music.

Finding referees for so many different topics was not easy, because we need in a referee the same overlap in expertise present in the papers. For this reason, the preparation of this special issue was not fast as we would have liked and we want to apologize with all the authors. We want also to thank Maurizio Rossi, editor in chief of this journal, for his proposal to us to be editors of this special issue, and Veronica Marchiafava, journal secretariat, for her patience, continuous commitment, and great help. Without Veronica this special issue would not exist.

And now enjoy the read, or, probably better for this special issue, *"bon appetit"*!

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Domestic Horticultural - Centric Lighting Design

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ABSTRACT

Coloured lighting is a vital factor for plant growth, inducing both photosynthesis, phototropism and photomorphogenesis. Detailed experimental studies on the photobiology of plant have already shown the importance of creating proper lighting receipts for different species, growth and developmental stages in order to obtain a good plant productivity and nutritional quality formation.

LEDs, nowadays, are a good tool for creating the proper lighting receipts composed by different narrow spectral power distribution combined for specific plants. Small dimension, long operating lifetime, great efficiency, digitally controllable features and optically controllable performances are also useful aspects for plants' lighting system development not only for laboratorial research experimentation, for aero-spatial and industrial food production but also in other filed such as domestic applications.

In this domain, the research aimed at defining requirements and features of a lighting fixture for food growing that could be prototyped in an easy and economical way. The requirements were derived firstly from a scientific literature review about agriculture and food science in order to define the preferred characteristics of lighting for food growing in terms of quantity, spectral power distribution, spatial distribution, direction, temporal distribution. More than this a a qualitative survey was performed in order to derive further product' specifications in terms of end-users' interests in the functionalities, dimensions, price and interface features of the system.

Finally, the solutions were further developed in two prototypes that meet the following requirements: mixing between the different channels, ability to create relations of flow between the channels, the overall dimensions. The prototypes were meant as design probes for evaluating the usability and the impact of the product before proceeding to the detailed design.

KEYWORDS

coloured lighting, spectral power distribution, LED lighting, horticultural lighting

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1. INTRODUCTION

Lighting and particularly coloured lighting is a vital factor that contributes to plant growth inducing both photosynthesis, phototropism and photo-morphogenesis. Detailed experimental studies on the photobiology of plants have already shown the importance of creating lighting receipts specific for different species' growth and development in order to obtain a good plant productivity and nutritional quality formation. LEDs, nowadays, represent a good solution for creating the proper lighting receipts composed by different narrow wavelength specifically combined for every plant. Small dimensions, long operating lifetime, great efficiency, digitally controllable features and optically controllable performances are also useful aspects for an horticultural – centric lighting not only for laboratorial research experimentations, for aero-spatial and industrial food production but also for educational, medicinal and therapeutic scopes [1-2-3]. More than this, domestic food farming is currently an increasing trend derived by both the emergent interest in eating healthy, genuine, km-0 and origin controlled food combined with a raising necessity of nature reconciliation through sustainable behaviours and responsible choices [4]. In this regard, an LEDs lighting system for home farming can be a possible solution especially in domestic environment lacking natural lighting or good climatic conditions, with limited or absent natural spaces as gardens, terraces and balconies.

2. RESEARCH AIM

The research scope is defining requirements and features of a lighting system for food growing in domestic environments, by investigating and proposing a practical and ready to make designed solution considering not only technological problems but also user oriented issues. If the hypothesis is that LEDs are creating the opportunity for an energy efficient, reliable and qualitative superior system for domestic gardening, this papers would like to contribute with a series of guidelines and a designed proposal for the realization of an easy, economic, efficient, functional prototype that could be used for experimental research scopes.
For reference, I compare the typical colors of the sweets packages in the US and Japan in Munsell notations and RGB variables (Figure 9 and Tables 1-3).

3. RESEARCH METHODOLOGY

The requirements of the proposed Domestic Horticultural – Centric Lighting system were derived firstly from a scientific literature review about agriculture and food science in order to define the preferred characteristics of lighting for food growing in terms of quantity, spectral power distribution, spatial distribution, temporal distribution and direction. A quantitative - qualitative survey was performed in order to derive further lighting system specifications in terms of end-users' interests and attitudes in using an LEDs based system for domestic cultivation. More than this, the aim was to gather insights in terms of desired features to better define a domestic horticultural-centric LEDs based lighting system.

4. LIGHTING REQUIREMENTS FOR PLANTS

According to the literature review, plants require light throughout their whole life-span from germination to flowering and seed production. Quality, quantity and duration are the most relevant parameters of growing light influencing in different way the plant performance [6]:

- *Light Quantity (Irradiance)* is the main parameter which affects photosynthesis, a photochemical reaction within the chloroplasts of plant cells in which light energy is used to convert atmospheric CO_2 into carbohydrate;
- *Light Quality (SPD - Spectral Power Distribution)* of the radiation: this aspect regards which portion of the light emission is in the Blue, Green, Red or other visible or invisible wavelength regions. These can be defined as *"primary colours"* and their mixture defines different SPD (lighting receipts) specific for each plant. For photosynthesis, plants have the maximum response for Red and Blue light. Light spectral distribution also has an effect on plant shape, development and flowering (photomorphogenesis).
- *Light duration (photoperiod)* is related to the developmental responses of plants to the relative lengths of light and dark periods and mainly affects flowering. Plants are very selective in absorbing the proper wavelength according to their requirements. The most important part of electromagnetic spectrum is called PAR (photosynthetically active radiation) which spread from 400 to 700 nm.

The fundamental problem to solve in the LEDs lighting engine design is to model different SPD (it means to identify the proper number and the driving current of the *"primary coloured LEDs"*) to optimize the plant growth in an efficient way: the main idea is that a controlled and engineered SPD would be much more beneficial for the plants rather than white light because it would allow to better control the flowering time, the high photosynthetic efficiency, the low heat stress in a more efficient and performance oriented way. The visible spectrum can be subdivided in several bands and each of them has a defined role in plant's growing and photosynthesis process [7]:

- *380–400 nm (ultraviolet A/visible light)*: the process of light absorption by plant pigments (chlorophylls and carotenoids) begins;
- *400–520 nm (visible light: violet, blue and green bands)*: peak absorption by chlorophylls occurs in this range and has a strong influence on vegetative growth and photosynthesis;
- *520–610 nm (visible light: green, yellow and orange bands)*: this range is less absorbed by the plant pigments and has less influence on vegetative growth and photosynthesis [8];
- *610–720 nm (visible light: red bands)*: a large amount of absorption occurs at this range, strongly affecting the vegetative growth, photosynthesis, flowering and budding;
- *720–1000 nm (far-red/infrared)*: germination and flowering is influenced by this range but little absorption occurs at this band.

The selection of the *"primary colours"* (in first approximation, good candidates are Red, Green-Yellow, Blue-Violet) is important to photosynthesis. In addition to this, it is also important to consider the relative proportion or *"Red:Blue" - "Red:Green:Blue"* ratios. Many studies [5] investigate the best mix of primary light sources to match them with the peaks of the absorbance curve of the plants [An example is reported in Figure 2].

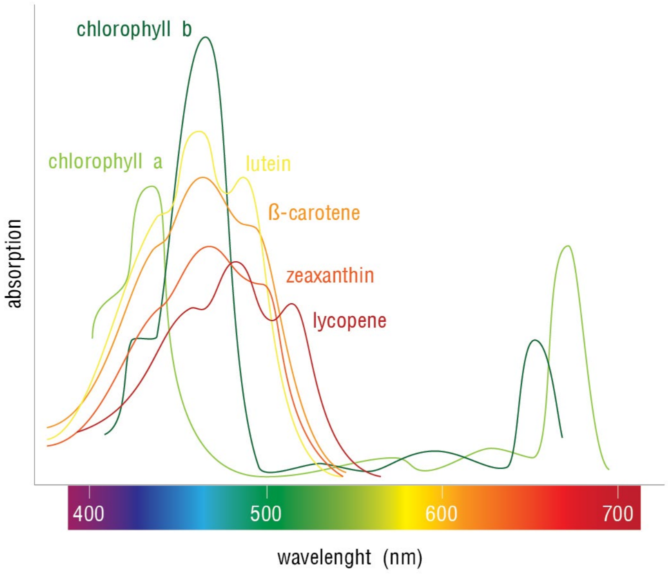

Figure 1 - Absorption spectrum of chlorophyll and other photosynthetic pigments. Adapted from Margherita Giacomozzi thesis "Cibele, Light for Food"

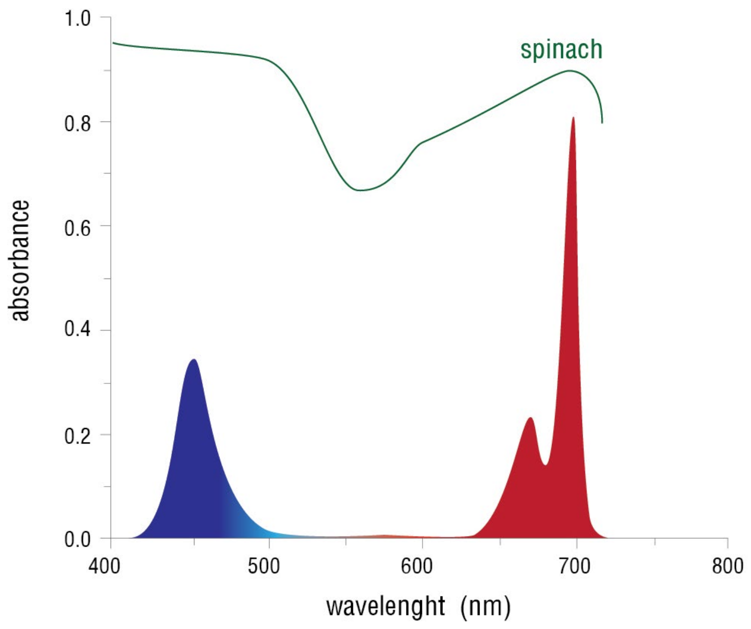

Figure 2 - Comparison between the SPD of three different LEDs and the absorbance spectra for the Spinach plant. Adapted from Margherita Giacomozzi thesis "Cibele, Light for Food"

5. USERS' REQUIREMENTS FOR DOMESTIC HORTICULTURAL-CENTRIC LIGHTING

5.1. PARTICIPANTS

For this study, 63 respondents (38.3% male - 61,7% female) took part in the survey. The age of participants can be divided in two categories: 24-34 years old (68,3%), 35-47 years old, (31.6%). Half of the participant was living in North Italy (50%) and the other half was spread in Europe (The Netherlands 8.3%, UK 5.0%, Spain 3.3%, Austria 1,7%, Belgium 1.7%, Germany 1.7%, Switzerland 1,7%,), east and far east (China 16.7%, Turkey 3.3%, South Korea 3.3%) and USA (3.3%).

The survey was directed to people interested in the growing - farming at home topic: the majority of the participants were architects, designers and engineers (34%) followed by educators, teachers and professors (17%), researcher (10%), psychologists and sociologists (7%).

5.2. USERS' ATTITUDES TOWARD DOMESTIC HORTICULTURAL-CENTRIC LIGHTING

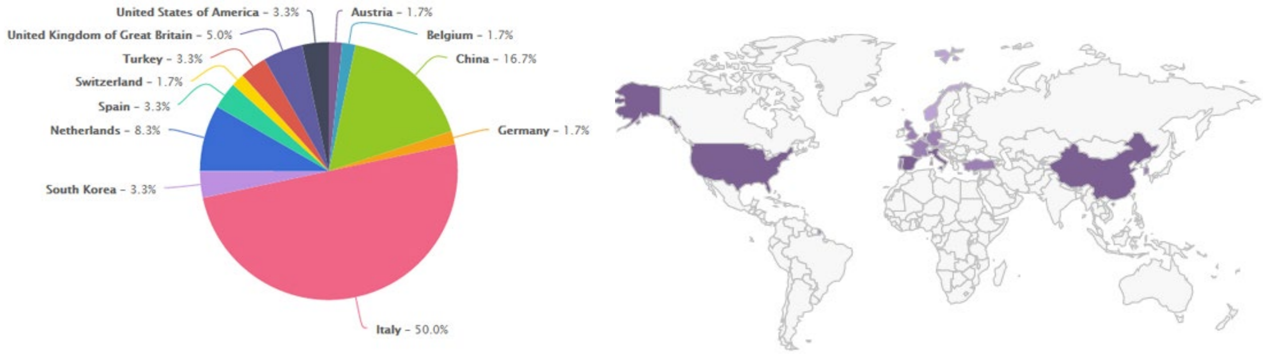

Figure 3 - Participants' distribution in the world

From the survey, a strong majority of the participants (71.5% rating equal or greater than 6) affirmed that they were inclined in eating genuine food intending self-grown, km-0, pesticide-free (ave. 7.3; std. dev. 2.8 on a 0 - 10 scale). In addition to this, the 65.6% were positively in favour and willing to cultivate fruits or vegetables in their home with an indoor growing system (ave. 6.2; std.dev. 2.5 on a 0 - 10 scale). Despite of this, the 52.5% were not particularly skilled in gardening and cultivating (ave. 4.3; std.dev. 2.7 on a 0 - 10 scale). This preliminary results shows some insights about the latent need of providing systems for gardening and food growing that help and support users with on-time information and feedback for better farming outcomes.

The 48,2% were interested in using an LEDs based system for cultivating indoor (ave. 5.8; std.dev. 2.6 on a 0 - 10 scale), primarily because of the lack of spaces such as garden and balconies (41.3%), and consequently because of poor natural lighting and bad weather conditions in winter. In addition to this, people were interested in using an LEDs based lighting system for ensuring the growth of food for their own consumption (39,7%), also appreciating the opportunity of cultivating (and eating) some species off season (33.3%) and considering the interesting possibility of experimenting and learning (25.4%). Other consideration regarded the educative and therapeutic purpose of horticulture at home (36.5%) that helps in stimulating children, adults and elderly people in their physical (exercise, sensory, stress release) psychological (accomplishment, confidence, biophilia hypothesis, connection with nature), intellectual (observation, experimenting, creativity, curiosity) and social skills (community, sharing).

Finally, LEDs were recognized as a more efficient technology for indoor growing compared to traditional lighting systems not only in terms of lower energy consumption but also in terms of the lighting quality provided that responds more precisely to plants' needs, thus defining a more productive growing system.

6. REQUIREMENTS FOR AN LEDS LIGHTING SYSTEM FOR DOMESTIC FOOD GROWING

From the scientific literature review and the survey, some requirements for a domestic horticultural-centric LEDs lighting system were defined. In particular, the research investigated features like dimensions, location and integration of the system in the domestic environment. In addition to this, the typologies of cultivation were explored and related to the proper lighting in terms of quantity, quality and duration for producing a congruous amount of species (not intensive industrial production), with particular interest in the efficiency of the LED based lighting system combined with good flavours, aromas and nutrients of the food. The exploration focused also on the homely feeling of the system considering the aesthetics, pleasantness, interest and domestic suitability. Considering the not professional users, the investigation focused also on the perceived functionality and the overall simplicity of the system (installation, use, cleaning/maintenance, control and management). [9]

6.1 DOMESTIC INTEGRATION: DIMENSION AND LOCATION PREFERENCE

The space required, considered available and useful for a domestic farming system was preferentially (49.1%) a *thin, vertical volume* (approx. 0.3 x 0.3 x 1.6 m) and a *cubic compact volume* (31.6%) (approx. 0.8 x 0.8 x 0.8 m) (Figure 4). This dimensions shows both to have an appropriate capacity for cultivating a proper amount of food and to be also compatible and harmonious with the other domestic furniture, fitting the system into the limited domestic space available. In relation to this, in condense high-rise apartment buildings the preferred room and location where to place the system were on the kitchen countertop (45%) or the pavement in any other available space of the house (38.3%), especially in the living and dining room. In other situations, such as villas and wider spaces, people suggested the use of a specific room such as a winter garden (20%), an old annex of the house or the basement / garage.

6.2 TYPOLOGY OF CULTIVATION AND LIGHTING NEEDS

From the survey the most interesting cultivation were:

- *vegetables* (73.3%) (Spinach, Swiss chard, Artichoke, Zucchini, Cabbage, Eggplant, Lettuce, tomatoes, cauliflower, fennel, celery, cardi, dandelion, broccoli head, endive, peppers, cucumbers, chicory, broccoli, turnip, pumpkin, leek);
- *spices and aromatic / medicinal plants* (61.7%) (cumin, marjoram, thyme, chives, oregano, basil, mint, parsley, rosemary, sage)
- *small-medium fruit plants* (51.7%) (strawberries, blueberries, raspberries, blackberries, currants).

Considering this list of desiderata, the lighting needs were derived from the scientific literature review and the lighting receipts (lighting quantity, quality and duration) were identified in order to be suitable and adaptable to the majority of plants by mixing the wavelength in an appropriate way and trying to limit the amount of different LEDs channels (primary colours) in order to reduce the overall costs. In Table 1, a summary of the typology of cultivation and related lighting receipts was provided with examples.

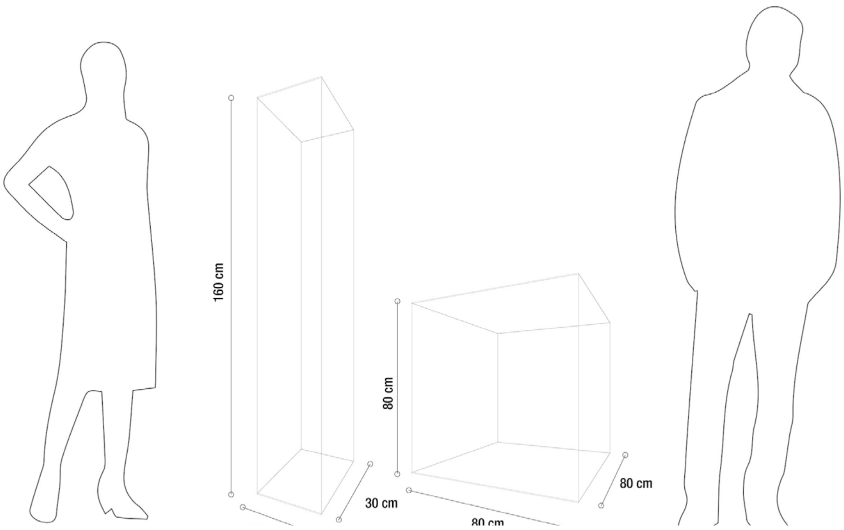

Figure 4 - Domestic integration: dimensions preference

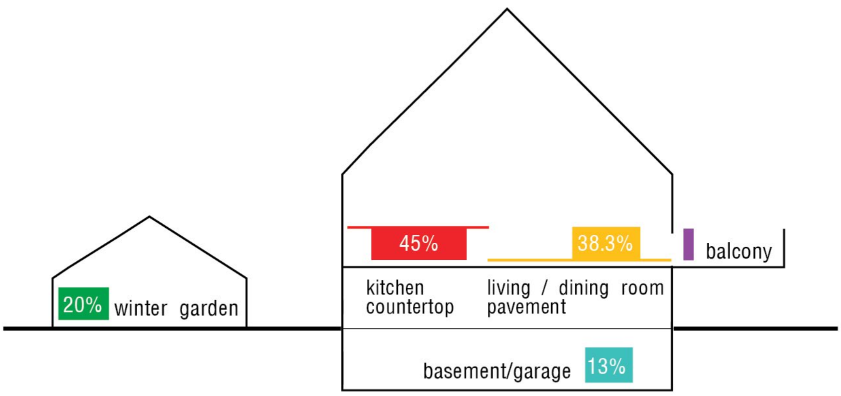

Figure 5 - Domestic integration: location preference

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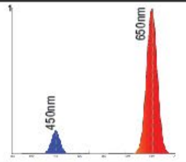
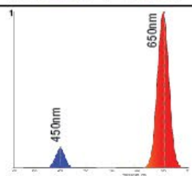
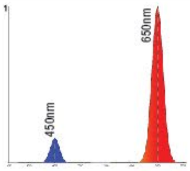
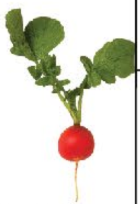
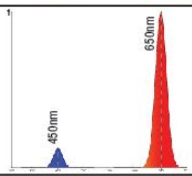
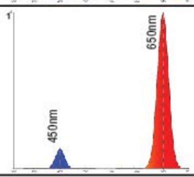
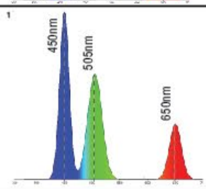
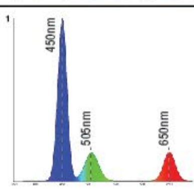
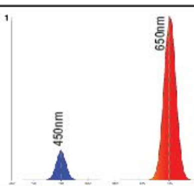
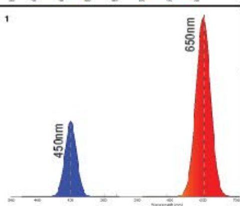
Table 1 - Typology of cultivation and related lighting receipts (quality, quantity, duration)

In comparison to the lighting receipts found in the literature review as reference (refer to Table 1), the authors selected one value of the peak position for each spectral band in order to develop the experimental lighting prototype characterized by extreme simplicity and reduced costs, adaptable to the domestic environment (avoiding dangerous UV or NIR

Type	Nomenclature	PROTOTYPE LED light source Dominant Wavelength (nm)	REFERENCE Light source Dominant Wavelength (nm)	Ratio Red:Blue %Red: %Green: %Blue	PAR (400 - 700 nm) μmol*photons* m^{-2}*s^{-1}	Photoperiod (light/dark) Hours	Spectral power distribution	Reference
	Lactuca sativa	450,650	450,635	8:1	200	18/6		[11]
 Lettuce	-	450,650	470,660, 670,680,690	10:1	250	18/6		[12]
	Raphanus sativus	450,650	450,635	8:1	200	18/6		[11]
 Radish	-	450,650	470,660, 670,680,690	10:1	250	18/6		[12]
 Spinach	-	450,650	470,660, 670,680,690	10:1	250	16/8		[12]
 Cucumber	Cucumis sativus Moskovskii Teplichnyi	450 505 650	450 - 500 500 - 600 600 - 700	17.5%: 40%: 42.5%	424	14/10		[13]
 Tomato	Starfire	450 505 650	450 - 500 500 - 600 600 - 700	15%: 17.5%: 67.5%	409	16/8		[13]
	Fragaria Ananassa Duch	450,650	455,640	7:1	200	16/8		[14]
 Strawberry	Fragaria vesca	450,650	450,630	3:1	100	16/8		[15]

spectral emissions), flexible to be used to grow different species (Table 2). In addition to this, particular care was given to the lighting uniformity which is stated as an important feature both for instantaneous and photoperiod lighting by the *"Lighting systems for agricultural"* standard published by ASABE (American Society of Agricultural and Biological Engineers). [10]

LED Colour	Dominant Wavelength (nm)	Spectral bandwidth at 50% $I_{rel\ max}$ (nm)
RED	650	25
GREEN	505	30
BLUE	450	20

Table 2 - Primary LED colour for horticulture light source

6.3 FUNCTIONALITY + SIMPLICITY + DOMESTICITY

People were confronted with three proposed solutions and some guidelines and insights were derived [16]. In particular, the main desired features were:

- *simplicity:* in terms of use, installation, cleaning/maintenance
- *domesticity:* compatibility with the domestic environment in terms of dimensions and location;
- *aesthetics:* pleasantness and interest
- *functionality:* in terms of effectiveness in food production
- *intelligence of the solution:* in terms of flexibility, modularity and upgradability
- *control and management:* simplicity in use and maintenance; flexibility in terms of information provided, adaptability to different cultivation; self-explanatory and helpful in providing knowledge.

The comparison and assessment made by the participants conduced to a reasoned selection of two different solutions that are specific for two different user targets, for two different kind of domestic cultivation and also show different features.

7. LEDS BASED DOMESTIC HORTICULTURAL – CENTRIC LIGHTING PROPOSAL

The solutions were further developed in two prototypes that meet the following requirements:

- mixing between the different channels;
- ability to create relations of flow between the channels;
- the overall dimensions;

The prototypes work as design probe useful for evaluating the usability and the impact of the product before proceeding to the detailed design.

7.1 DOMESTIC HORTICULTURAL LAMPSHADE

This solution [Figure 6] hides the intelligence and the lighting performance into a designed lighting fixture which is both decorative and functional: it can be used for experimenting a small scale cultivation and for helping not so *"green-fingered"* users in taking care of their plants (especially in winter time). More than this, when the user is not interested in using it for cultivation, it can be reversed in a normal lighting fixture or it can create particular lighting atmospheres in the domestic environment. This solution is suitable for *"naïve"* cultivators and amateurs.

The prototype achieves two different functions: light for plants growing and light for illumination of the environments. For this reason the device uses both a RGB LED strip and a strip with warm white LEDs (3000K). It allows to adjust its height in order to better adapt to different plants and also to different levels of growth in an efficient way (Figure 7).
It is composed by the following part:

- RGB LED strip with 26 light diodes in SMD (Surface-Mount Device) package;
- warm white with whit 48 light diodes in SMD package;
- reflector in high diffusive material (MCPET – Microcellular PET) composed by a mixing chamber for blending the different colours and a central diffuser that scatter the light emitted directly from the LED source;
- plastic box with a round shape that includes all the other optical part and light source;
- a plastic transparent diffuser with a high coefficient of transmission;
- A constant voltage LED driver: the current intensity is set by a resistor on PCB (Printed Circuit Board) and the different ratios between the channels is achieved by PWM (Pulse-width modulation) technique.

7.2 DOMESTIC HORTICULTURAL CABINET

This solution [Figure 8] integrates the intelligence and lighting performances in a lighting engine designed to hack and re-adapt a cabinet system that can be placed in storage rooms hidden from the domestic environment or in a dining /

living room integrated with other functions. It is a modular, upgradable, flexible solution, suitable for cultivating different species and farming a reasonable amount of food. The prototype is composed by the following part:

- RGB LED strip with 8 light diode in SMD package;
- Reflector in high diffusive material (MCPET);
- Plastic box with a rectangular shape that includes all the other optical part and the light source;
- A plastic transparent diffuser with a high coefficient of transmission;
- A constant voltage led driver: the current intensity is set by a resistor on PCB and the different ratios between the channels is achieved by PWM technique.

As shown in the Figure 9, the prototype has been realized in a single module. The lighting appearance depends of the different lighting receipts realized by setting the different ratios between the Blue and Red channel as described in Table 1.

8. CONCLUSIONS

This paper focused on setting the requirements, envisioning some insights, proposing some guidelines and defining LEDs prototypes of Domestic Horticultural-Centric Lighting design based both on the scientific review and on users' feedbacks, assessment and elicited observations. The released final prototype has been designed and built to be tested in a real environment. The survey was conducted on a reduced amount of subjects, but it can be hypothesized that the results can foreshadow emerging needs that in the future will be of interest to the broad masses of users.

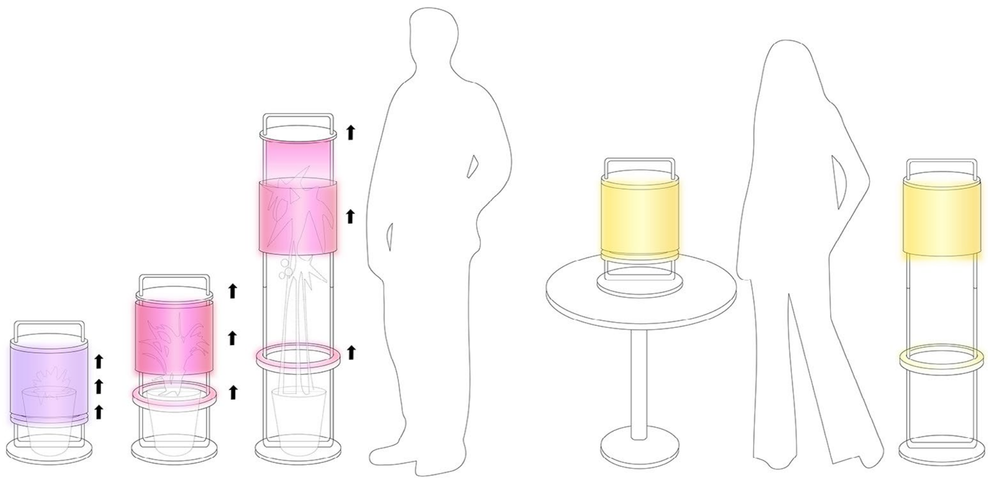


Figure 6 - The Domestic Horticu Lampshade: a double func horticultural / decorative lig system

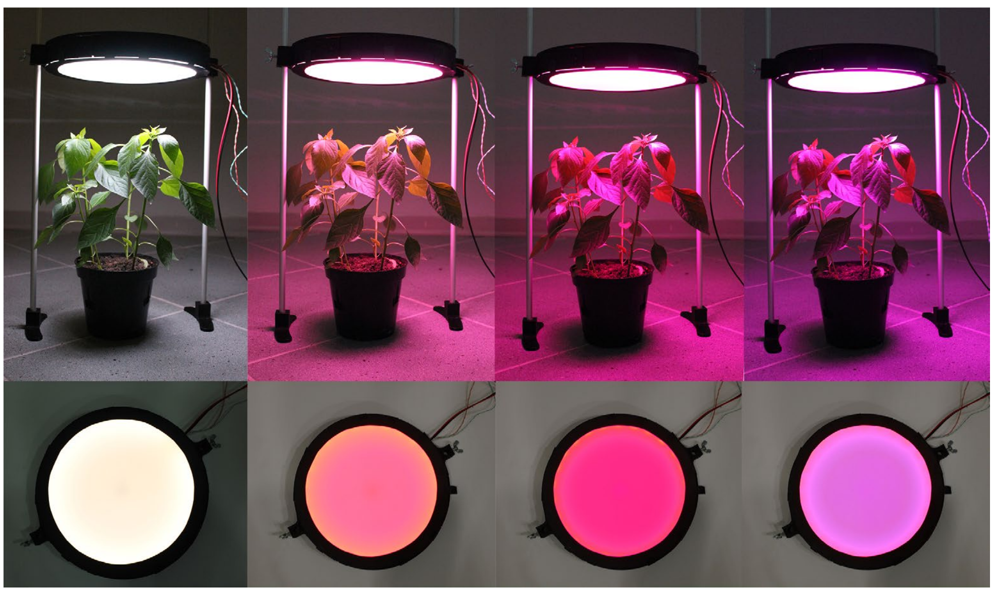


Figure 7 – The flexible Lighting Engine Prototype of the Domestic Horticultural Lampshade

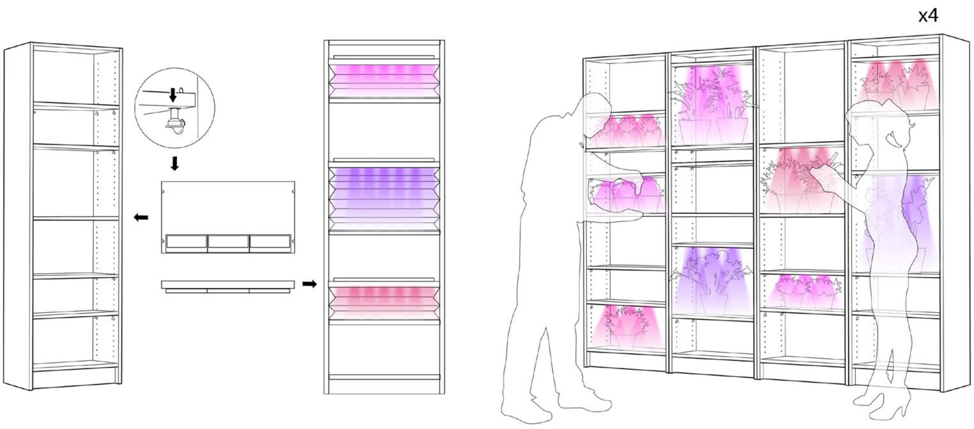


Figure 8 - The Domestic Horticultural Cabinet: modular scalable furniture hacked with an horticultural lighting engine

Figure 9 - The modular Lighting Engine Prototype of the Domestic Horticultural Cabinet

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