AALBORG UNIVERSITY
COPENHAGEN

Study Board of Media Technology
Frederikskaj 12
2450 København SV
Danmark

Semester Coordinator:
Georgios Triantafyllidis
gt@create.aau.dk

Secretary:
Lisbeth Nykjær
lny@create.aau.dk

Title

DALIA; A DYNAMIC ARTIFICIAL LIGHTING TOOL FOR THE DEVELOPMENT OF COMMUNICATION AND SOCIAL INTERACTION ABILITIES AMONG TODDLERS ON THE AUTISM SPECTRUM DISORDER

Programme
Msc. Lighting Design

Semester
LiD10, Spring 2020

Project Period
February 1st- June 31st 2020

Semester Theme
Master Thesis

Supervisor(s)
Marc Fontoynont

Project Group no.
N/A

Members

Sergio David Hernández Pascual

Abstract

Autism Spectrum Disorder is a life-long neurodevelopmental disorder characterised by deficits in communication, social interaction and repetitive sensory-motor behaviours which affects one in every hundred people in Europe (Lord et al. 2018; Foundation UEFA pour l'enfance, FIRAH, and Garnier 2017; Barthélémy et al. 2019; Autism Europe 2020).

Although there is no cure for Autism, studies suggest that early support intervention, behaviour therapies and family support can lead to the development of skills in communication and social interaction among individuals on the Spectrum, extending the possibility of a better quality of life (Barthélémy et al. 2019).

As visual perception is one of the most preserved sensory systems among the ASD population; this thesis explores the use of artificial lighting as a tool for the development of joint attention, communication and social interaction abilities among children on the Spectrum.

This project argues that light is the most apparent visual stimuli for humans and, by challenging the use of artificial lighting beyond its primary function (to provide visibility), proposes the design of DALIA; a dynamic artificial lighting tool. Which, by using it during support interventions on learning environments can promote joint attention, communication and social interaction skills among toddlers on the Spectrum.

DALIA arise as a possible answer to the principal hypothesis of this project: Can artificial lighting be used as a tool for the development of communication and social interaction abilities among toddlers on Autism Spectrum Disorder?.

Literature review, empirical evidence and involvement of professionals on ASD during the research and design development stages of the project reveals that there is an opportunity to use artificial lighting as an educational tool of people on ASD.

As there is a lack of evidence-based research regarding the connection of light and Autism; this thesis proposes a protocol for testing DALIA and, finalises addressing prospects of future work which can reveal more data about the relationship of light and individuals on the Spectrum.

THIS PAGE HAS BEEN INTENTIONALLY LEFT BLANK

DALIA

A **Dynamic Artificial Lighting** tool for development of communication and social interaction abilities in children on the **Autism Spectrum**

a master thesis by

SERGIO DAVID HERNÁNDEZ PASCUAL

to obtain the grade of

MSc. in LIGHTING DESIGN

supervised by

MARC FONTOYNONT

AALBORG UNIVERSITY
COPENHAGEN

STUDY BOARD OF MEDIA TECHNOLOGY
Master's Programme in Lighting Design
June, 2020
Copenhagen, Denmark

CONTENTS

PREFACE

Abstract III
Acknowledgements IV
Personal Motivation V

INTRODUCTION
Introduction 1
4 Structure and Methodology

CHAPTER I
Understanding Autism 5
6 Background
15 Sensory Perception
19 Autism and Lighting?
27 Chapter Conclusions

CHAPTER II
DALIA Design 29
31 Design Drivers
34 Lighting as a Tool, Cases Review
39 The Concept Behind: A System
43 Design Development
57 Co-Design

CHAPTER III
Testing DALIA 63
65 Methods
68 Procedures

CLOSURE
Conclusions 71
72 Future Research

List of Figures 73
References 77
Annexes 81

LINKS

Please scan this QR code to have access to this document as a digital flip-book or, click on this link.

Please scan this QR code to visualise a digital poster of DALIA or, click on this link.

Please scan this QR code to visualise a video summary of this project or, click on this link.

Abstract

Autism Spectrum Disorder is a life-long neurodevelopmental disorder characterised by deficits in communication, social interaction and repetitive sensory-motor behaviours which affects one in every hundred people in Europe (Lord et al. 2018; Foundation UEFA pour l'enfance, FIRAH, and Garnier 2017; Barthélémy et al. 2019; Autism Europe 2020).

Although there is no cure for Autism, studies suggest that early support intervention, behaviour therapies and family support can lead to the development of skills in communication and social interaction among individuals on the Spectrum, extending the possibility of a better quality of life (Barthélémy et al. 2019).

As visual perception is one of the most preserved sensory systems among the ASD population; this thesis explores the use of artificial lighting as a tool for the development of joint attention, communication and social interaction abilities among children on the Spectrum.

This project argues that light is the most apparent visual stimuli for humans and, by challenging the use of artificial lighting beyond its primary function (to provide visibility), proposes the design of DALIA; a dynamic artificial lighting tool. Which, by using it during support interventions on learning environments can promote joint attention, communication and social interaction skills among toddlers on the Spectrum.

DALIA arise as a possible answer to the principal hypothesis of this project: Can artificial lighting be used as a tool for the development of communication and social interaction abilities among toddlers on Autism Spectrum Disorder?.

Literature review, empirical evidence and involvement of professionals on ASD during the research and design development stages of the project reveals that there is an opportunity to use artificial lighting as an educational tool of people on ASD.

As there is a lack of evidence-based research regarding the connection of light and Autism; this thesis proposes a protocol for testing DALIA and, finalises addressing prospects of future work which can reveal more data about the relationship of light and individuals on the Spectrum.

Acknowledgements

The development of this project could not happen without a support network of people that got directly or indirectly interested on this project:

I thank Beatriz de Miguel; whom, through her everyday work as a support caregiver of children on the Spectrum, inspired me to understand the difficulties that the population on ASD faces daily and encourage me to develop DALIA and, for her continuous support, insights and feedback during the development of this thesis.

To Marc Fontoynont, my thesis supervisor, for his insights and advice to carry out this project.

I would like to thank the professionals on ASD: Beatriz Ruiz, Carmen Piédrola, Carmen Caro, Elena Gil, Eva Mesa and Juana Hernández; who shared their knowledge and perspectives about Autism and their openness to the ideas proposed on this project.

To my family and friends back in my home country, Mexico. Whom through distance, have managed to support me during the development of the project and the whole process of studying a master degree abroad.

Special thanks to Tapio Rosenius, Miguel and Pablo from Skandal for allowing me to use POET during this project and his insights and support during this process; to Manuel Pantoja from REVR, for helping me out to visualise DALIA digitally to provide a closer view of its potential.

Lastly, to my colleagues at Lighting Design Collective; Mahdis, Paloma and Victor who their words of encouragement help me out to keep the pace during the development of this project.

Personal Motivation

Selection of research topic for writing this Master Thesis was similar to a Design Thinking process, where the outcome is an evolution of ideas, personal growth and continuous back and forward of initiatives (Darbellay, Moody, and Lubart 2017).

The first thesis subject attempt I did, was to address values of dynamic lighting on the built environment by analysing and understanding the outcome of dynamic lighting on the urban context for society. What are the inhabitants receiving in exchange for having "blinking lights" on their environment? It was one of the initial research questions.

I did not felt engaged and confident enough to develop such matter, so after a while, I drop it off. Nevertheless, while moving forward on the research, two concepts caught my attention:

- Possibility of lighting to generate value for society.
- During a discussion about the research with Tapio Rosenius, he mentioned whatever the research is about; I should make it count, referring to make it worth for me and others. I took his observation as a responsibility I should take care.

Second trial arose after attending lighting conferences such as IALD Enlighten Europe 2018 in Barcelona, and Professional Lighting Design Convention 2019 in Rotterdam, where concepts linked to experience design, experiential lighting and user experience were frequently cited as pillars of lectures. If one takes a look into the Proceedings of PLDC 2019 (Ritter 2019); the concept of Lighting Experience as a liveable relationship between user and light capable of creating long-term memories and meaning for people (Coxon 2015, 14), can be found repeatedly among lectures abstracts.

By repeatedly listening to such concepts, I got intrigued about the context in which we, as Lighting Designers, use the idea of experience. Are we creating experiences as the speakers argue?, Is possible for a person to create a long-term memory trough lighting as a foundation?, Aren't we using the concept of experience as a marketing tool vaguely?. Hence, I initiated a literature review about Experience Design.

While reviewing Experience Design: Concepts and Case Studies, edited by Peter Benz; I found Linda Leung paper: Experiential Equality and Digital Discrimination. In which Leung argues the persistent inequality and users discrimination on the design fields and how

"User-Centered Design (UCD) promotes the discrimination of users as a part of its practice; that is, delineating between audience groups and the including or excluding them accordingly".
(Leung 2015, 47)

Fig. 0.1. | Disruptive lighting on the built environment. Light-art piece by Lighting Design Collective is in continuous change, rendering patterns generated by real time data inputs like weather or people flow.

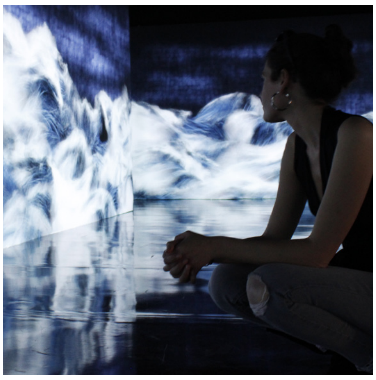


Fig. 0.2. | Person experiencing teamLab Black Waves exhibition. Experience becomes a long-term memory which can be used on the future as a reference knowledge to confront new scenarios.

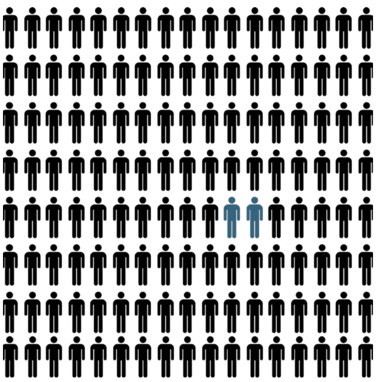


Fig. 0.3. | People on Autism are under risk of marginality. One on hundred people are on the Spectrum currently in Europe.

technology is not, against the common thought, the best tool to avoid discrimination of specific social groups. This approach marked me, setting the foundations for this project by awaking interest of work for those who are under the risk of social marginalisation.

At that moment, and after a bit more than twelve months of my first attempt, the dots started to connect. As my partner works as a teacher of children on the Autism Spectrum Disorder (ASD) allowed me to know sensory difficulties that this group of people face daily.

> "Autism provides us with a different outlook on the same world because the sensory processing functions in Autism differ considerably from those of the 'normal' population".
> (Bogdashina 2010, 15)

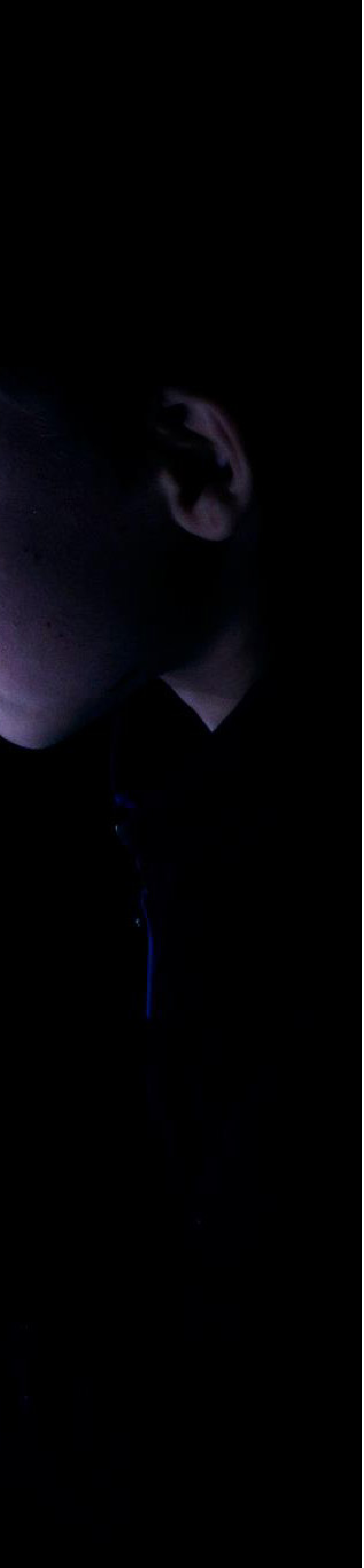
Individuals on the Spectrum face continuous marginalisation and discrimination by the built environments we live in, as these are not designed considering the specific needs of people on the Spectrum.

By taking out the most of each iteration, the following concepts became the pillars for this research: Lighting (from a disruptive approach) as a tool, experience as a method for creation of functional memories on people, and create social value by focusing on people under risk of marginalisation.

By merging these concepts, DALIA was born; a project which aspires to create a lighting based learning tool for children on the Spectrum, by understanding how they experience artificial lighting and, how this experience can work as a tool to develop life skills for social integration and communication.

INTRO-
DUCTION

Fig. 0.4. | Kid playing and interacting at Antonin Fourneau installation 'Water Light Graffiti'



Introduction

One in every hundred people in Europe are on Autism Spectrum nowadays (Autism Europe 2020b), recent research suggests that this ratio is even higher among seven to nine-year children, one in 89 / 12,2 per 1000 (ASDEU Programme and Posada de la Paz 2018). The proportion has increased for the past decades, and the forecast does not seem to be much brighter in the near future. Although screening programs and intervention methods have improved, the origin causes of Autism are still uncertain (Barthélémy et al. 2019).

Autism is a lifelong condition that affects people regardless of ethnicity, culture, race or socioeconomic group (Autism Europe 2020b; Lord et al. 2018).

Researchers describe ASD as a neurodevelopmental disorder characterised by deficits in communication, social interaction, cognitive abilities and sensory difficulties like hyper or hypo sensitivity on taste, touch, smell, audition and vision (Foundation UEFA pour l'enfance, FIRAH, and Garnier 2017; Barthélémy et al. 2019; Autism Europe 2020a).

Studies suggest the visual system the most preserved among the population on the Spectrum (Kana et al. 2006; Gaffrey et al. 2007). Hence, as light is the natural and most obvious visual stimuli on people (for those who are not visual impaired); Can light and lighting be adopted as a stimulus on people in the Spectrum for engagement?.

Many tools based on visual perception are used nowadays on Autism interventions and treatments; like communication through pictograms. However, only a small percentage (almost null) uses light beyond a functional tool for providing visibility when there is darkness.

Artificial light has changed the way we perceive our world and, has become a key role-player during night-time hours. From street-lighting to disruptive approaches like media façades and lighting festivals (Fig. 0.4.), light and lighting allows us to design environments which enhance human experiences, propitiate interaction between people and the built environment and even to communicate messages (Pop 2012; Jackson et al. 2015; Rosenius and Signify Lighting University 2017). Can these approaches be somehow useful in Autism?.

Current technology is pushing the boundaries and roles of light and lighting. So how and to what extent can lighting affect the developmental process of toddlers in Autism?.

There is no cure for Autism condition; nevertheless, early detection, appropriate education, treatment, intervention, behaviour therapies, and support for persons on the Spectrum and their families can decrease core symptoms over time. Hence, developing abilities in joint attention, communication and social interaction on early stages of life can lead to a better quality of life for individuals and their families (Barthélémy et al. 2019).

On these grounds, the following research questions arise:

- Can artificial lighting be used as a tool for developing lifelong skills in toddlers on Autism?
- What difficulties could present the use of light as a visual stimulus?
- How does the visual stimuli should be in order to propitiate a positive experience among this population?.

> Can artificial lighting be used as a tool for the development of communication and social interaction abilities among toddlers on Autism Spectrum Disorder?
>
> Project problem statement

By addressing the previous research questions and problem statement, this project explores the current understanding of Autism and sensory perception difficulties of the condition while suggesting hypothetical scenarios in order to establish a framework and lighting design principles for the development of an artificial lighting-based tool.

As a possible solution to the problem statement, the project addresses the design development of DALIA; a Dynamic Artificial Lighting tool for usage in support interventions of children on the Spectrum.

Although it has not been possible to manufacture DALIA and perform a test study with children on the Spectrum due to COVID 19 pandemic, the design developed has been presented to professional caregivers of toddlers on Autism in order to obtain feedback from the design proposal.

To finalise, the thesis suggests a test protocol of DALIA on users and addresses possible future research regarding the relationship of artificial lighting and Autism.

Structure and Methodology

The project structure follows a linear process comprised of four main phases: background analysis, design development, test protocol and conclusions (fig. 0.5.).

Under a "Blue Ocean Strategy" perspective, (although no economic benefits are pursuit on this research), the background study and analysis of the project reveals the existence of an opportunity to use artificial lighting as a strategy for the development of communication and social interaction abilities on people on ASD.

The first section of the project presents the current understanding of Autism in order to set the context of the project, followed by an analysis of sensory perception and visual processing peculiarities related to the Spectrum and its relationships with light and lighting.

Then, through interviews with professional caregivers of people on Autism; the project explores the relationships between Autism and light, and main concerns of the caregivers regarding the use of artificial lighting as a stimulus.

By arguing the use of light beyond its primary function: "to provide visibility" and the fact that, the visual system is the most preserved among people on Autism (Kana et al. 2006; Gaffrey et al. 2007); this thesis proposes the use of Dynamic Artificial Lighting as a tool for the development of communication and social interaction abilities among children on the Spectrum. Here the "Blue Ocean", as relationships of Autism and lighting have been hardly explored.

The second chapter proposes the design of DALIA as an answer to the "Blue Ocean" found. It argues the design from a conceptual level by establishing design drivers, lighting principles, symbolism and, defines Dynamic Artificial Lighting as a system to achieve the goals of the project. Subsequently, this section presents a review of cases in which lighting has been used on similar frameworks to this project, followed by a detailed design development.

Chapter three focus is to establish a test and evaluation protocol for future opportunities, in which space, subjects, procedures and evaluation methods to follow are addressed.

To conclude, the final chapter elaborates over main findings and considerations over the development of the project and the possibility of using artificial light on special education programs and addresses research questions for future developments regarding Autism and lighting.

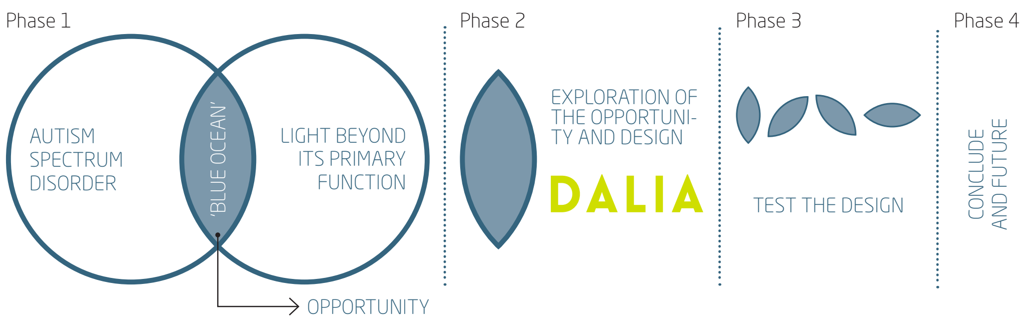


Fig. 0.5. | Process model.

UDERSTANGIND AUTISM

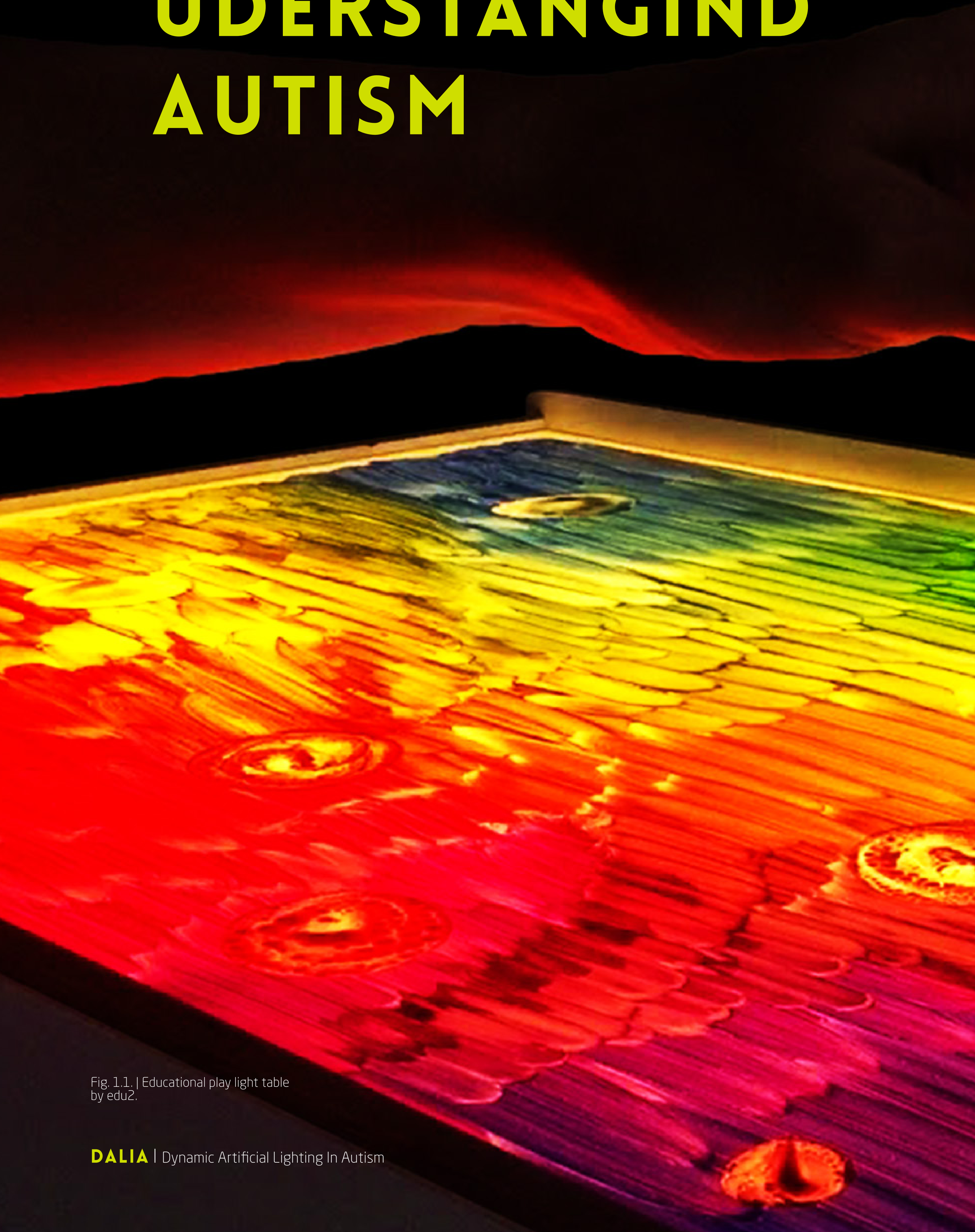
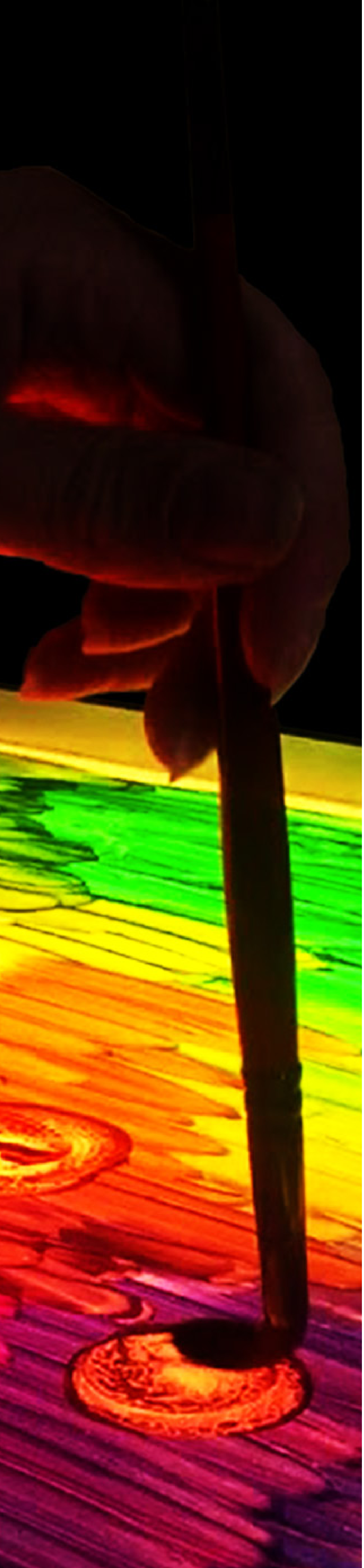


Fig. 1.1. | Educational play light table by edu2.



Background

Studies concerning Autism dated from the first mid of 20th century when Leo Kanner provided the first formal documentation about the condition on his paper Autistic Disturbances of Affective Contact (1943). Based on observation of conducts among eleven children diagnosed with childhood psychosis Kanner concluded that Autism was a form of childhood schizophrenia developed by the children due to being raised by cold, detached and rigid parents (Holaday 2012; Howlin 2005).

Kanner defined the condition as a "combination of extreme autism, obsessiveness, stereotypy and echolalia" (Kanner 1943, 249).

Almost 80 years after Kanner's paper, understanding and definition of the condition has changed substantially. Nowadays, researchers and community understand Autism as a spectrum of neurodevelopmental disorders characterised by affecting communication, social interaction and repetitive sensory-motor behaviours. A lifelong condition which, in most cases, affected individuals will require some kind of support over their entire life (Lord et al. 2018).

Autism is also characterised by being a spectrum, meaning that conducts and symptoms vary on kind and intensity from individual to individual. Hence, there is no "one size fits all" kind of support intervention and even on the same person, assistance needed will vary over time due to cognitive development, learning of abilities and self-experience (Barthélémy et al. 2019).

Causes

Is well known that the best way of unravelling a problem is to understand its causes. Although researchers have concerned about finding the origin of Autism, causes remain uncertain.

To date, there are two lead theories about ASD causes; the first one suggests that Autism has a strong genetic basis (Folstein and Rutter 1977), so it is an inherited condition probably caused by gene mutations (Wolff 2004; Wing 1981). The second one; and probably the most studied in the last 20 years, suggested by Munkin & Isaev (1975), considers the origin of Autism as an organic deficiency of brain function (Wing 1981) associated to an accelerated brain development in early stages, leading to an altered connectivity among some areas of the brain (Lord et al. 2018).

Recent neuroimaging studies have revealed specific patterns of brain development in toddlers that later received Autism Spectrum Disorder diagnosis.

Abnormalities on brain development leads to specific Autistic behaviours along the first 36 months of life; as a cascade effect which ends up as a disrupted connectivity on the brain and consolidation of Autistic behaviours, as shown on figure 1.2. (Piven, Elison, and Zylka 2017; Hazlett et al. 2017).

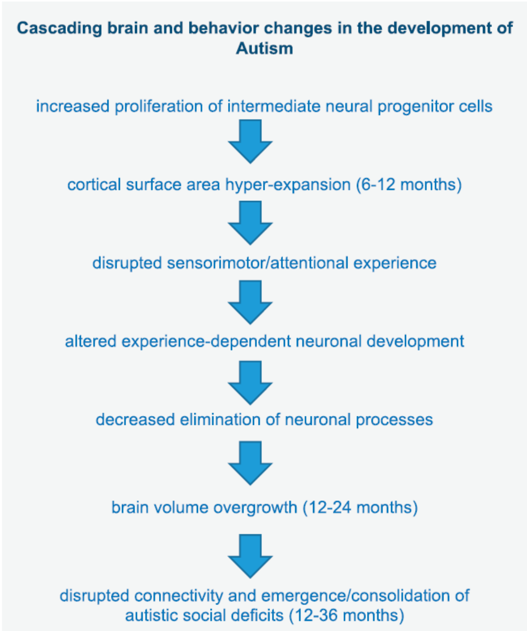


Fig. 1.2. | Cascading brain and behaviour changes in the development in Autism. (Piven, Elison and Zylka 2017, 5)

Personal remarks.

Disrupted connectivity and brain abnormalities can lead to alterations on the visual system of individuals on the Spectrum, such as shadow processing or face recognition (Behrmann, Thomas, and Humphreys 2006). As light being a visual stimuli, its perception might result altered, therefore visual perception and visual processing on Autism will be discussed later on this document.

Diagnosis Criteria and Symptoms

Autism Spectrum Disorder diagnosis is based on behaviours, as no biological markers have been confirmed yet. Although people on Autism have disharmonic behavioural profiles varying from one individual to another, symptoms affect two main core domains; social communication and restricted, repetitive sensory-motor behaviours (Lord et al. 2018).

Among the existing diagnostic instruments, Autism Europe refers to two manuals which are the most common used by professionals worldwide. The International Classification of Diseases (ICD; currently the 11th edition available) published by the World Health Organisation and the Diagnostic and Statistical Manual of Mental Disorders (DSM; currently 5th edition available) published by the American Psychiatric Association, being the last one the most referred on the literature reviewed (Autism Europe n.d.).

DSM-5 points out two primary contexts on the Autism Spectrum Disorder; persistent deficits in social communication and social interaction and restricted, repetitive patterns of behaviour, interests or activities. For each one, a series of 3 and 4 criteria correspondingly are grouped covering one or more specific atypical behaviours that are usually found on individuals on Autism, as shown in figure 1.3. (American Psychiatric Association 2013).

According to DSM-5, in order to be diagnosed on the Spectrum, an individual should have or have had met the three criteria regarding the social communication and social interaction context and at least two out of the four criteria of restricted, repetitive patterns of behaviour, interests or activities (Lord et al. 2018; American Psychiatric Association 2013).

CONTEXT	CRITERIA	BEHAVIOUR
A. PERSISTENT DIFFICULTIES IN SOCIAL COMMUNICATION AND SOCIAL INTERACTION	A.1. Deficits in social-emotional reciprocity; ranging from abnormal social approach and failure of normal back and forth conversation through reduced sharing of interests, emotions, and affect and response to total lack of initiation of social interaction.	• Abnormal social approach • Failure of normal back and forth conversation • Reduced sharing of interests • Reduced sharing of emotions / affect • Lack of initiation of social interaction • Poor social imitation
	A.2. Deficits in non-verbal communicative behaviours used for social interaction; ranging from poorly integrated verbal and non-verbal communication, through abnormalities in eye contact and body language, or deficits in understanding and use of non-verbal communication, to total lack of facial expression or gestures.	• Impairments in social use of eye contact • Impairment in the use and understanding of body postures • Impairment in the use and understanding of gestures • Abnormal volume, pitch, intonation, rate, rhythm, stress, prosody or volume in speech • Abnormalities in use and understanding of affect • Lack of coordinated verbal and non-verbal communication
	A.3. Deficits in developing and maintaining relationships appropriate to developmental (beyond those with caregivers); ranging from difficulties adjusting behaviour to suit different social contexts through difficulties in sharing imaginative play and in making friends to an apparent absence of interest in people.	• Deficits in developing and maintaining relationships, appropriate to developmental level • Difficulties adjusting behaviour to suit social contexts • Difficulties in sharing imaginative play • Difficulties in making friends • Absence of interest in others
B. RESTRICTED, REPETITIVE PATTERNS OF BEHAVIOUR, INTERESTS OR ACTIVITIES	B.1. Stereotyped or repetitive speech, motor movements or use of objects; such as simple motor stereotypies, echolalia, repetitive use of objects, or idiosyncratic phrases.	• Stereotyped or repetitive speech • Stereotyped or repetitive movements • Stereotyped or repetitive use of objects
	B.2. Excessive adherence to routines, ritualised patterns of verbal or non-verbal behaviour, or excessive resistance to change.	• Adherence to routine • Ritualised patterns of verbal and non-verbal behaviour • Excessive resistance to change • Rigid thinking
	B.3. Highly restricted, fixated interests that are abnormal in intensity or focus.	• Preoccupations, obsessions like with numbers, letters, symbols, colour, time-tables, historical events • Interests that are abnormal in intensity and narrow range of interests • Focused on the same few objects, topics or activities • Being overly perfectionist • Interests that are abnormal in focus and excessive in non-relevant or non-functional objects • Attachment to unusual inanimate objects or carrying around unusual objects
	B.4. Hyper or hypo reactivity to sensory input or unusual interest in sensory aspects of environment.	• Tolerance to pain • Preoccupation with texture or touch • Unusual visual exploration / activity • Hyper / Hypo sensitivity in all domains of sensory stimuli (sound, smell, taste, vestibular, visual) • Unusual sensory exploration with objects

Fig. 1.3. | Table showing the contexts, criteria and typical behaviours established by DMS-5 for ASD diagnosis.

Although DMS-5 points out that the symptoms must be present in early childhood, is not explicit about the recommended age for assessment and screening of an infant. Researchers have found that screening instruments are more predictive for children as young as 18 months and in the more severe cases is possible to diagnose from 12 months of age (Lord et al. 2018). Hence, it suggests that early diagnosis a key for a prompt intervention, leading to increase the possibilities substantially for children to have a better quality of life.

Currently, only two countries in the European Union have active early detection programmes: Norway and Spain. These countries use the modified checklist for Autism in toddlers, which, together with DSM-5, is the most used for early detection (ASDEU Programme and Posada de la Paz 2018).

"Children with Autism grow up to be adults with Autism".
(Charlton 2016)

Personal remarks.

Inclusion of sensory disorders into diagnostic criteria such as the presented by DSM-5 (sensory disorders were not present on previous versions of DSM) is leading to explorations and development of new sensory tools for support interventions among researchers and Autism community. This inclusion suggests that light and lighting (considering them as sensory stimuli) can function as a tool for support interventions.

By accepting sensory disorders as a part of the Spectrum, and by taking in account observations that suggest early intervention, this project will focus on working among infants between 3 - 10 years old as its suggested as the best age for the individuals to develop lifelong abilities and skills (Barthélémy et al. 2019).

Support Interventions

As a lifelong condition, is understood among professionals, researchers and community that there is no cure or definitive treatment for Autism (Barthélémy et al. 2019). Support offered for people on the Spectrum is widely referred on literature as intervention; understanding it as a way of acting through specific methodologies to improve one or more behaviours or problems.

Although many different types of interventions have been carried out over the past seventy years, only a few are supported by evidence as most of the scientific research has focused on the diagnosis and Autism causes (Barthélémy et al. 2019).

Autism Europe addresses as the main framework for interventions to apply them in parallel to individuals normal developmental process; and focus on develop behavioural, social interaction and communication skills, in order for the people on the Spectrum to face daily living situations and achieve a better quality of life (Autism Europe 2020; Barthélémy et al. 2019).

It is common among the population to believe that symptoms of Autism disappear over time when a person receives support; when in fact, is the result of strategies developed by the individual to cope with specific situations based on previous experiences, which means that the symptoms remain but are under control by the individual. Hence, if the person faces a new situation in which no strategies exists, atypical behaviour might appear (Howlin 2005).

As an example, a person on Autism who does not show apparent symptoms is used to take a train at 8:00 a.m., and the display on the station shows that this train is cancelled while the individual is waiting, he or she might do not read the display, due that in the learned routine the train is always at 8 a.m.; therefore, the individual might wait for the train to arrive for elapsed time; as is not a situation faced before, symptoms might appear such as: anxiety, not asking to other travellers why is no train coming or isolation. Those are adaptive skills that the individual need to learn.

In order to develop adaptive skills, main intervention goals are: language and communication skills, social behaviour and interaction abilities, self-care, self-awareness as well as motor and academic skills (Howlin 2005; Lord et al. 2018).

Although methodology and variety of interventions is as broad as Autism Spectrum itself, evidence has shown that in order to be effective, interventions must include four fundamental principles (Barthélémy et al. 2019; Wing 1981):

- Individualisation: no single treatment is equally useful for all people.
- Structure: Adapting the environment to maximise each person potential by offering predictability and stability.
- Intensity and generalisation: Nor be sporadic or short term, nor based on a pre-determined number of hours or sessions. Systematic manner on a daily basis should be applied.
- Family participation: Family and close relative circles should take an active role in the support system of the individual.

Interventions such as Treatment and Education of Autistic and Related Communication Handicapped Children (TEACCH), Denver Model (Early Start Denver Model) and Learning Experiences: an Alternative Program for Preschoolers and Parents (LEAP) are the most recognised among the variety of interventions available nowadays. Conduct based, developmental and educational theories have shown to be effective through evidence-based methodologies (Salvadó Salvadó et al. 2012; Howlin 2005; Lord et al. 2018).

TEACCH Model.

Based on cognitive-social learning theory, "Autism culture", taking into account individual abilities and neuropsychological development among Autism peers and, being the main difference from other methodologies a framework based on structured learning. Introduced by Dr Erich Schopler in 1966 at the University of North Caroline in Chapel Hill is now worldwide known and reference for many interventions and educational systems, its key features are as follows (Howlin 2005; Salvadó Salvadó et al. 2012):

- Structured environment and activities in order to be understandable for individuals like: environment organisation, daily routines and sequence of events during the day, individualisation of tasks and frameworks.
- Use of individual strengths such as visual abilities and interests to balance other difficulties on their development.
- Motivation for learning and focus by using their very own specific interests.
- To promote the use of spontaneous functional communication.

Denver Model.

Designed for early intervention on toddlers, characterised by being based under a constructivist approach which children have an active role-play on the construction of their very own mental and social structure through interpersonal affective, motor and sensory experiences.

Exchange and influence of experiences with peers generates an active and inclusive environment.

Initial assessment of the individual establishes short-term goals arranged in four levels (from 12 to 48 months) based on the development of the individual and particular ASD profile; for the most advanced visual and motor goals and, for the less advanced, social and communication objectives. Intervention program covers communication areas, socialisation, imitation, play, cognition, motor skills and autonomy (Salvadó Salvadó et al. 2012).

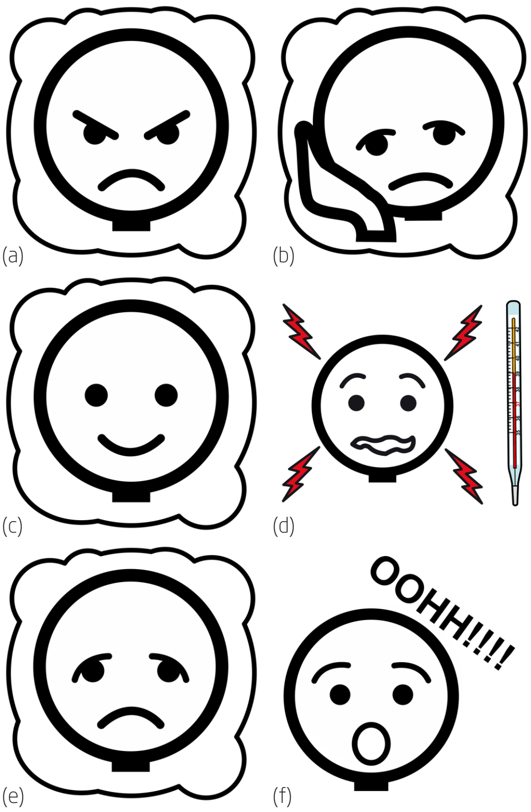


Fig. 1.4. | Pictograms as tools for visual exchange communication and learning of concepts, in this case, emotions: (a) anger, (b) boredom, (c) happiness, (d) illness, (e) sadness, (f) surprise. Figures by Aragonese Centre for Augmentative & Alternative Communication.

Leap Program.

The program uses methods such as conduct analysis, incidental learning, visual exchange-based communication (fig. 1.4.) and mediated instructions by peers and it focuses on the development of cognitive-academic, adaptive, autonomy communicative and socio-emotional areas on children (Salvadó Salvadó et al. 2012).

On its grounds its an inclusive educational program in which children on Autism attend to regular classroom with neurotypical children based on their natural developmental level. Parallel to their regular teachers, the children have a specialised education professional who brings support on specific development of abilities and works as a mediator.

On its research; ABA versus TEACCH: The Case for Defining and Validating Comprehensive Treatment Models in Autism, Callahan K. et al. (2010), proved that models and programs could be effective if applied into scholar context; and even more valid if methodologies and techniques are combined (Salvadó Salvadó et al. 2012). This framework is currently the methodology followed in Spain, where the educational program for children on the Spectrum is a combination of TEACCH, Denver and LEAP models(de Miguel García 2020).

As many factors are involved during the development of a person who has been on interventions, measurable outcome remains uncertain. Nevertheless "follow up studies into adulthood suggest that the severity of the core Autism symptoms decreases over time, and many individuals show marked improvements in social and communication skills as they grow older" (Barthélémy et al. 2019, 10). Is estimated that 10 to 30% of adults on Autism only uses simple phrases to communicate and have IQ's on the range of intellectual disability (Lord et al. 2018).

Professionals and researchers suggest that interventions should be available as soon as possible, with specific emphasis on the early diagnostic and early interventions, which should start at 18 months as has been proved that the most significant gains are made by children to have begun to make progress in language by the age of 3 years (Lord et al. 2018).

Personal remarks.

Support interventions for individuals on Autism are complex, deep studied theories developed by experienced researchers and professionals on the field. The objective of this project is to develop an artificial light-based tool for usage during support practices. Therefore it can not be considered as an intervention or treatment itself.

Techniques and procedures of support interventions vary from program to program, having in common the use of the visual system as a mechanism for interaction and non-verbal communication among caregivers and individuals on Autism, such as pictograms (fig. 1.4.). Surprisingly, none of them considers the usage of light & lighting beyond its primary function (to provide vision when it is dark). This thesis explores the possibility to use artificial lighting as a pedagogic tool among individuals on the Spectrum, considering light as the natural and most apparent stimuli of the visual system among humans (and probably most life-forms).

Language, communication and social interaction are dominant objectives of support interventions among literature reviewed. Is understood that a person who develops abilities on these areas will be able to perform better on the rest of developmental fields like behaviours, self-care, self-awareness and cognitive learning. Hence this project focus on using lighting as a tool to promote communication and social interaction among children on the Spectrum.

Lighting sources and mains to control them allows us (Lighting Designers) nowadays to explore artificial light beyond its primary function. Hence, within the context of this project, artificial lighting could promote specific behaviours among children on ASD, leading to the development of life long skills and eventually an opportunity to have a better quality of life.

The following table (fig. 1.4A.) correlates the diagnosis contexts established on the DSM-5 with artificial lighting applications (and control technologies), followed by the formulation of a behavioural hypothesis as an expected outcome of the utilisation of artificial lighting as a tool for developing life long skills on ASD individuals.

DSM-5 Diagnosis Criteria	Artificial Lighting Applications	Behavioural Hypothesis
A.1. Deficits in social-emotional reciprocity; ranging from abnormal social approach and failure of normal back and forth conversation through reduced sharing of interests, emotions, and affect and response to total lack of initiation of social interaction.	Arrays of LED sources can be an "engagement agent" by using cameras, movement detection, and computer vision algorithms to mimic user movements to control brightness, colour and patterns of light sources. Lights can act as a "mirror" or react in specific ways by counting persons on the field of view (FOV) of the camera, inviting the user to establish/invite other persons to participate in the action to obtain suggestive visual stimuli (fig. 1.5.).	Adjusting lighting properties and display patterns based on people and movement detection will create engagement and encourage social interaction among ASD children.
A.2. Deficits in non-verbal communicative behaviours used for social interaction; ranging from poorly integrated verbal and non-verbal communication, through abnormalities in eye contact and body language, or deficits in understanding and use of non-verbal communication, to total lack of facial expression or gestures.	If usage of the light-based tool becomes an attractive enough experience for the individuals to generate a "desire" of using it, but control relies on a third-party (caregiver), it can promote verbal or non-verbal communication for requesting it. Audio sensors could detect specific pitch or volume of sound and activate the display of specific lighting patterns, maybe to warn that there is no need for screaming or if a voice is to low to encourage to speak louder (fig. 1.6.).	Lighting schemes will encourage communication (not necessarily verbal) among ASD children and their peers or caregivers.
A.3. Deficits in developing and maintaining relationships appropriate to developmental (beyond those with caregivers); ranging from difficulties adjusting behaviour to suit different social contexts through difficulties in sharing imaginative play and in making friends to an apparent absence of interest in people.	By displaying patterns or specific combinations of colours, could lead to encourage imaginative play, for example, a combination of green and blue hues, imitating a nature environment scene (fig. 1.9.). By linking control algorithms to real-time data like weather, could lead to an understanding of the environment and how it affects the user.	Environment responsive lighting will propitiate a better understanding of the relationship of the user with the environment and encourage imaginative play.
B.2. Excessive adherence to routines, ritualised patterns of verbal or non-verbal behaviour, or excessive resistance to change.	Visual aids through light which shifts automatically as per specific routines during the day; for example, in a school environment 30 minutes before playtime lighting shifts from colour A to colour B, being displayed B when is playtime. Hence, the person would know when it is time or how much time is missing for something to happen (fig. 1.8.).	Lighting will provide information about specific routines promoting independence and awareness among ASD children.
B.4. Hyper or hypo reactivity to sensory input or unusual interest in sensory aspects of environment.	Lighting scheme adaptation based on the sensory profile of the user; for example, brightness can be adaptable when a person is hypersensitive to light. Easy configuration per caregiver according to each individual (fig. 1.7.).	Personalisation of lighting schemes according to the user needs will reduce the risk of adverse results among the ASD population.

Fig. 1.4A. | Table showing correlations between DSM-5 diagnosis contexts and artificial lighting applications, followed by formulation of behavioural hypothesis.


Fig. 1.5.


Fig. 1.6.

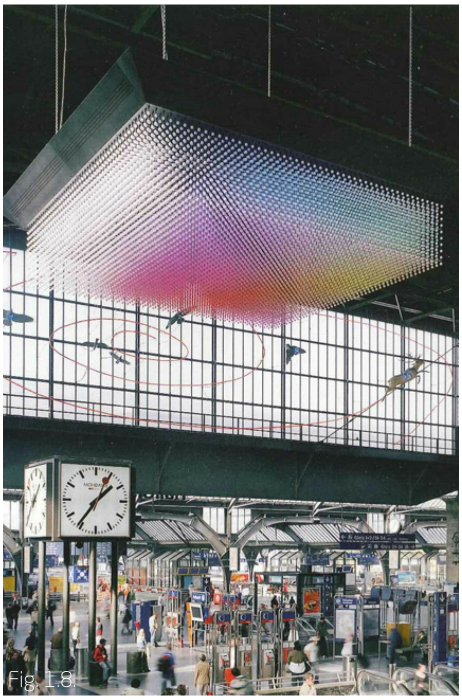


Fig. 1.8.


Fig. 1.7.


Fig. 1.9.

Fig. 1.5. | Anonymous by Lighting Design Collective. The participants silhouettes are projected into the façade of the building, its projection gets distorted by participants own voice by a bespoke software that analyses volume and pitch. Acting as an anonymous 'mirror'.

Fig. 1.6. | bruumRuum! by Artec 3 and David Torrents. Giant microphones on the public realm allows people to speak through them, its voice modifies the colour and brightness of the fixtures recessed on the ground.

Fig. 1.7. | OSC commands on a tablet can be send to the control software of the lighting in order to modify some of the parameters like brightness, colour, pattern, etc. It allows customisation easily and on real time.

Fig. 1.8. | NOVA Display System by Martina Eberle and Christoph Niederberger. Bespoke software controls the display of patterns, colours and effects on the three dimensional array of light sources.

Fig. 1.9. | The way of the sea by teamLab at Borderless Museum. Projections over man-made lily-pads allows the user to transport itself from a dark room to some kind of under-sea experience, allowing imagination to flow.

Sensory Perception

From a biological and evolutionary approach, humans as other living forms rely on information coming from the outer and inner worlds (environment and invironment correspondingly) in order to survive and reproduce at the most fundamental levels (Barth, Giampieri-Deutsch, and Klein 2012). The sensory systems of the organism collect data; the complexity of the systems vary accordingly if the living form is a bacteria or a human; nevertheless, in all cases, sensory systems are well-tuned adapted mechanism to receive a wide range of stimuli (Barth 2012).

As humans, we have developed sensory organs and cells capable of responding to the environment and inviroment stimuli. External or exteroceptive organs allow us to respond to stimuli like light, temperature or pain. They can be divided into distance senses like vision, hearing and smell and contact senses like taste or touch. Propioceptor systems allow us to receive stimuli from our inner body, like the vestibular system, which allow us to know the position of the body and movement (Bogdashina 2007). Hence, senses are our "windows" to the world (Bogdashina 2007).

Although we have different sensory systems is well know that we receive 75% to 80% of the information through vision. Individuals that have one or more senses impaired compensate the missing sense with another one, like visually impaired people who rely on their auditory system in order to understand their environment.

Information received through our "windows" is meaningless itself, in order to understand and shape a response to the data received, we need to translate it at our brain through a cognitive process. Therefore, perception is an active and ever-changing process called sensory perception; the response to the stimuli is our behaviour (Barth 2012).

When born, we are capable of receiving stimuli like images and sound, but we do not know what they mean. We learn to interpret the images and sounds based on experience, so by a few months old, we can understand and differentiate between the voice or face of a person. It is crucial to understand that giving meaning to stimuli and shaping responses is a lifelong process.

Interpretation of the stimuli at the cognitive level relies on imagination, memory and previous experiences of each individual, so each person perceives the world on their very own way. All the information received by our senses takes shape at our brain, where we build up our mental image of the world. As our brain is not capable of processing all of the stimuli received at a time, it discriminates the most relevant of each situation and discards the rest (Bogdashina 2007).

French philosopher Etienne Bonnet Condillac (1715-1780) suggests that our knowledge, judgements and thoughts come from our sensory experiences; it can be understood that sensory experiences and sensory perception shapes our personality.

> "Autism affects every domain of human experience: from sensation and perception to motor behaviour, emotion, communication and cognition".
> (Robertson and Baron-Cohen 2017, 681)

Sensory Processing Difficulties Associated to Autism

People on the Autism Spectrum live in the same physical world than neurotypical individuals and receive similar stimuli from the environment. Nevertheless, their perception of the world can be far distinct compared to the one perceived by neurotypical people. Researchers, as Delacato (1974) suggests that abnormalities on the sensory perception are the leading cause of atypical behaviours of people on Autism (Bogdashina 2007).

Is estimated that atypical sensory experiences are present in 90% of people on Autism by affecting every sensory system like taste, touch, audition, smell and vision (Robertson and Baron-Cohen 2017). Difficulties in sensory processing due to neurological differences like low-level changes in neural circuity dedicated to perceptual processing and deficit in general domain cognitive processes such as attention and decision making have been pointed out by researchers as primary causes of atypical sensory perception on Autism (Hegde 2015; Robertson and Baron-Cohen 2017).

Most well known sensory abnormalities on Autism are hyper or hypo sensibility to stimuli, causing variations on the "volumes" of perception and difficulties on interpreting stimuli. Olga Bogdashina refers to Nony, a woman on Autism that when young had difficulties to walk on the streets during sunny days; as reflected light on the pavement or windows and showcases hurt her eyes. So she had to run in order to hide at any dark spot she could find or at least cover her eyes (Bogdashina 2007). That is photopic hyper sensibility.

Besides hyper and hypo sensibility, Bogdashina (2007) suggests eight main sensory experiences (or sensory processing difficulties) in Autism. Table on page 17 (fig. 1.9A) suggests the relationship of Bogdashina's sensory processing difficulties with visual processing complications associated with Autism, and proposes lighting schemes to cope with the difficulties.

Visual Perception in Autism

> "I think in pictures. Words are like a second language to me. I translate both spoken and written words into full-colour movies, complete with sound, which runs like a VCR tape in my head. When somebody speaks to me, his words are instantly translated into pictures".
>
> (Dr Temple Grandin, Thinking on Pictures 1995)

Studies proved the visual sense is the most preserved on Autism and that in some cases, is even more developed than in neurotypical individuals(Kana et al. 2006). As the case of Dr Temple Grandin who is on the Spectrum and widely known for her autobiography "Thinking in Pictures", and influence to improve quality of life of people on the Spectrum.

Bogdashina's Sensory Experiences	Visual Processing Complications	Proposed Lighting Schemes
Literal perception. Difficulties on discrimination of relevant and irrelevant stimuli. Difficulties on distinguishing information from main plane and background known as Gestalt perception.	Processing of complex visual scenes where extracting essential information is hard, or integrate the different parts into a single scene.	Use of high-contrast to facilitate integration of the different elements on a scene or distinguish the relevant information on it. For example, when it is time for dinner, lighting should highlight dinner table on high-contrast in order to focus attention on the specific task.
Hyper or hypo sensibility. Sensory channels are either too open or to closed, each person requires different intensity of stimuli. Sensibility fluctuation. Sensibility shifts from hyper or hypo randomly on the same person.	Avoid participation in visual tasks when the stimuli are too bright or too dark, or loss of attention due to shifts on the sensibility.	Adaptation of brightness, colour or movement patterns of light according to the individual's thresholds and sensory profile.
Fragmented / distorted perception. Excess of selectivity towards a stimulus; when there is too much information to be processed, people on Autism are not able to break down the information and analyse it by parts in order to process it.	Visualisation of specific elements on a scene and failure when integrating the different elements into a "whole".	Use of light layers to present the different elements of a scene gradually.
Sensory agnosia or inability to interpret a specific sense / stimulus.	As the visual system is the most preserved research indicates that it is unlikely that the individual will not perceive visual stimuli.	Adaptation of lighting schemes according to individual preferences and perceptions.
Delayed perception.	Interpretation of a stimuli might take more time compared to neurotypical individuals due to the cognitive process.	Slow speed or elapsed time for lighting shifts and movement of patterns in order to allow the user to process the changes.
Sensory overload. Leading to atypical and repetitive behaviours due to inability to process information or brake it down.	Overload of visual processing due to an excess of visual stimuli leads to difficulties to understand and specific scene.	Avoid excess of light sources and changes on lighting and preferably usage of indirect lighting over direct.

Fig. 1.9A. | Table showing correlations between Bogdashina's sensory experiences, visual processing complications and proposed lighting applications.

Brain regions associated with visual processing are active on people on Autism, even when performing activities of low-level imagery like mathematical operations or simple reading (Kana et al. 2006). These leads to believe that visual stimulation plays a vital role in the development of communication and other skills of people on Autism (Bogdashina 2007).

Although the visual system is well preserved on individuals on the Spectrum, some processing difficulties exist, such as:

- Weak central coherence and global processing. Most individuals on Autism are particularly attentive to details, which at some extent is as a strength, it also leads to difficulties on seeing "the full picture", this is referred as "they see the trees before the forest". These leads into a partial perception of the environment and its understanding (Behrmann, Thomas, and Humphreys 2006).

- ASD individuals present difficulties on face processing and discrimination of genders through face recognition, as well as failing in understanding facial expressions and emotions which commonly are expressed by facial gestures (Behrmann, Thomas, and Humphreys 2006).
- Sensitivity to motion. Studies have shown atypical processing of dynamic visual stimuli like understanding direction of moving dots on a screen (Robertson and Baron-Cohen 2017; Behrmann, Thomas, and Humphreys 2006). Understanding movement requires global processing which fails on people on the Spectrum; the response time to moving stimuli can be longer than in neurotypical individual (Behrmann, Thomas, and Humphreys 2006).
- Failure on shadow processing on bi-dimensional images. Shadows are useful for understanding three-dimensional representations of an object, becoming a source of information for the global processing of the scene. On Autism, research has shown that shadows are not used as an information source as they are perceived as a part of the object on the scene leading to confusion (Becchio, Mari, and Castiello 2010).

Visual perception can is a process which involves physical and cognitive tasks, based on the three-stages model of human visual information processing by Colin Ware (fig. 1.10.) (Ware 2009). Is understood that processing difficulties on Autism occurs at stage 3, where high-level perception is required, and cognitive processes happen. Nevertheless people on the Spectrum have equal or superior performance on stages 1 and 2 than neurotypical individuals (Behrmann, Thomas, and Humphreys 2006; Becchio, Mari, and Castiello 2010; Robertson and Baron-Cohen 2017).

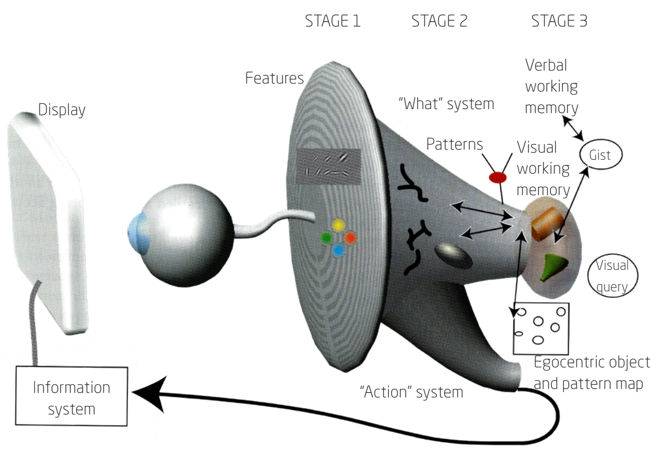


Fig. 1.10. | Three-stage model of human visual information processing. Adapted from original by Colin Ware; where:
Stage 1. Information is processed to extract basic features of the environment. Low level imagery.
Stage 2. Active processes of pattern perception pull our structures and segment the visual scene of different colour, brightness, texture and motion.
Stage 3. Information is reduced to only a few objects held in visual working memory by mechanisms of attention to form visual thinking.

Personal remarks.

The literature reviewed suggests that ability of people on the Spectrum for identifying the orientation of simple, luminance-defined gratings, recognition of details, find figures and patterns, identification of high pixel saliency regions, colour and orientation (all of this inherent to light) can be exploited on their benefit in order to develop of life long skills.

Although stage 3 of the visual information processing model of Ware is the most affected, some persons on the Spectrum are visual thinkers, like Dr Temple Grandin.

Autism and Lighting?

Although the visual system is one of the most preserved sensory systems among the population on Autism (Kana et al. 2006), evidence-based research about its relationship with light (both natural and artificial) its limited.

As knowledge regarding how light affects individuals in the Spectrum is limited, findings on the literature reviewed are the following:

- Hyper and hypo-sensitivity to light are frequent among the population on Autism and responses to light stimuli can vary from atypical behaviours like repetitive patterns of movement (such as flapping arms) to fascination on switching on/off the artificial light sources of a space. Other effects are people shielding their own eyes or hiding on dark spots. Nevertheless, specific causes of hyper and hypo-sensitivity to light remain unknown (Bogdashina 2007).
- Lower thresholds than neurotypical individuals on the perception of light sources flickering; some studies refer specifically to fluorescent lamps as in some cases the frequency is below 60hz and the sound emitted by the ballasts (Colman et al. 1976). It is necessary to note that fluorescent and incandescent lamps are out to date and LED light sources are replacing them (fig. 1.11.), hence effects of new lighting technologies on individuals on the Spectrum needs to be studied.
- Individuals on the Spectrum tend to focus their attention to specific light patters produced on the environment like reflections on surfaces, caustics caused by light refraction while trespassing materials like glass (fig. 1.12.), or the reflection of light on dust particles on the air (Gil Morán 2020).
- Specific hues could impact behaviours positively among some individuals, like the usage of blue light when a person is on an episode of anxiety (Sensing 2020).

In order to extend the understanding and possible implication of artificial light on Autism, empirical knowledge from professionals who work daily with persons on ASD has been collected for this project. By conducting a total of seven interviews with intervention and education support professionals, where one of the profiles was discarded due to little experience on ASD.

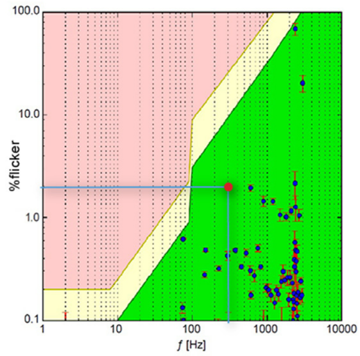


Fig. 1.11. | % Flicker vs. Flicker frequency on LED light sources by EldoLed. Higher frequencies reduces flickering on light sources

Fig. 1.12. | Caustics caused by light refraction. Raytrace installation by Benjamin Hubert.

Profiles of Interviewees

Selected profiles correspond to professionals who work directly with children on ASD as support teachers on educational environments, psychologists who develop behavioural interventions and educational policies advisors on government.

All the professionals hold at least a professional degree on special pedagogy and three of them have master's degree on special education, with an average professional experience of 15 years on the subject, being the minimum ten and maximum 23 years. All of them, residents in Spain where they develop their professional activities currently. Spain included dedicated classrooms (Aulas TEA) into regular public schools since the mid 90's decade as a method of inclusion and social integration.

Methodology

Interviews were designed as an open dialogue between interviewer and interviewee, meaning closed questions were avoid. Conversations were held individually; in Spanish through online video call, using Microsoft Teams application. Average duration of each interview was 59min, and all the participants agreed on the recording of audio during the meeting, transcripts of the conversations can be found on the annexes section of this document (in original language).

Each interview was structured as follows:

- Presentation and thesis project explanation.
- Questions and discussion regarding the role and importance of light and lighting for Autism on educational and interventions framework.
- Lighting approaches beyond the primary functional use of light (to provide visibility when dark); from now on referred as 'Atypical Lighting Approaches', were presented to the interviewees, approaches included the use of light as communication, interactive and reactive lighting, light and light as an experience and emotions enhancer.
- Discussion based on atypical lighting arise by questioning possible negative impacts, usage among educational framework and developmental areas that could be supported by light.
- Closure.

Discussion

Role and importance of light and lighting on ASD educational/intervention environments.

Light is present on educational and intervention environments, whether it is natural, artificial or mixed schemes. Interviewees agree its use on these spaces is merely functional: to provide general visibility and for performing tasks; in less importance is used as a secondary educational tool and mostly embedded on toys.

Elena Gil describes her classroom as a space with plenty of windows and almost no walls, with additional artificial light for support, in which the light sources are fluorescent lamps. She argues it is possible to regulate incident natural lighting on the interior of the space through curtains and by switching on/off the artificial light sources, all at once, no dimming (Gil Morán 2020). The scheme described might be appropriate for a classroom in which every user is neurotypical; however, when some of the students are on the Spectrum, it is not. These lighting scheme needs to be evaluated, as an excess or lack of light could cause atypical behaviours on children on ASD due to hyper or hypo sensitivity to light.

“It seems to be some sort of ‘fight’ about switching on/off the lights of the classroom among two of my students on ASD”.
(de Miguel García 2020)

Most of the interviewees believe the educational system (on Spain) does not give importance and value to light and lighting when creating a new ASD classroom on schools (from health-care point of view). In most cases, these classrooms are adaptations of spaces that were not in use at the educational centre; therefore, transformation (from design to execution) is low budget and following the same guidelines than neurotypical classrooms. Although Juana Hernández mentions that lately, acoustic isolation on ASD classrooms has been considered in order to avoid sound stimuli, meaning sensory awareness is starting to be considered (Hernández 2020).

Lighting influence on ASD individuals is not considered when setting classrooms infrastructure; hence, atypical behaviours are common, disabling to some extent, proper flow of the learning process of children on the Spectrum.

There is a clear need inside ASD classrooms; considering individual needs in order to find a balance which allows the children to focus and feel comfortable. Possibility to trigger “scenes” or different zones with different light levels, so each person finds its comfort area (Hernández 2020). Implementing lighting control systems and LED light sources could be a first step forward.

“The kids get distracted by reflections caused by the sun rays through the windows”.
(Gil Morán 2020)

“After every task, I allow one student to hide into a dark spot on the classroom, a tent we have, as he argues that the light fixtures hurts his eyes”.
(Piédrola 2020)

“If the student arrives before to me to the classroom, he switches on all the lamps and opens the curtains; afterwards this bothers the rest of the kids”.
(Ruiz Casas 2020)

Tendency of children on Autism to focus into light-emitting objects over those which are not.

In order to develop a specific task or learn a new skill, attention of toddlers necessary; this is a complex mission when working with children on ASD, mostly due to their restricted interests and sensory difficulties.

Interviewees were questioned if based on their experience, there is a propensity among children on the Spectrum to focus on light-emitting objects over those who are not. According to their responses, it seems that this hypothesis is real and not limited to light, but also sound; in both cases not restricted to light or sound emitting objects. Elena Gil refers a case in which one kid was fascinated and entirely focused on observing how dust particles on air shimmers when hit by light, to the point that there was no way to call back his attention to focus on the class (fig. 1.13.).

Interviewees agreed on using light as an “attention caller”; nevertheless, it was mentioned that the effectiveness is variable from individual to individual due to own specific sensory profiles and sensibility. In general, light-emitting objects generates fascination among the students, but in some cases, this fascination gets transformed into an obsession; like the dust particles mentioned by Elena Gil.

Fig. 1.13. | Dust particles suspended on air shimmers when hit by light

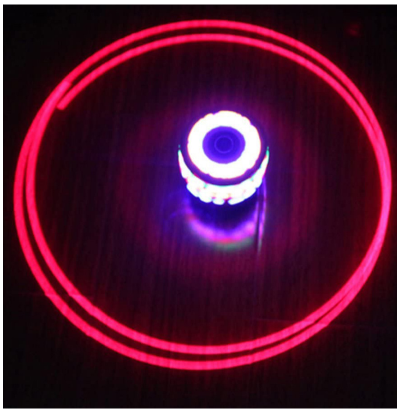


Fig. 1.14. | Spinning peg-top with integrated lighting toy.

Fig. 1.15. | Bouncing ball, shimmers when bounced.

Fig. 1.16. | Lighting sticks with integrated fiber optics, shimmers and changes hue when agitated.

Although "obsession" risk mentioned, most of the interviewees use light-emitting objects on their practice, being the most recurrent objectives of using them as follows:

- Reward. Under behavioural approaches works as a positive reinforcement, if the individual performs a task correctly, a light-emitter toy is granted, could be another kind of toy or game, but seems to be a tendency for the light emitters (Mesa 2020).
- Encourage communication. Being the individual fascinated with a ball that shimmers in colours when bouncing (fig. 1.15.), the toddler will ask for it to the support professional, not necessarily using verbal communication, "but pointing to it or looking it and then looking at you" (Piédrola 2020).
- Social interaction. Encourage playing with peers with "light sticks" (fig. 1.16.) or hand-lamps (Ruiz Casas 2020).

In most of the cases, mentioned objects are not tools designed for educational purposes; their usage has been adapted by the professionals to motivate the development of skills. Hence its pedagogic uses might be limited. Tools such as mobile phones or personal tables arise as well; nevertheless, its usage is not that common as by definition are "personal devices", so social interaction, which is one of the pillar skills to develop, is limited with those tools.

Tools such as Lighting Tables (widely used in Montessori education) or Pictogram Room (Herrera et al. 2012), arise as existing resources which fundamentally operates through light, nevertheless it seems that are not very popular among the professionals. These tools will be discussed further on this thesis at the DALIA Design section.

Before the following discussion topics, atypical lighting approaches were introduced to the interviewees.

Atypical lighting as an "attention caller" and tool for develop life-long skills on toddlers on ASD.

As people on ASD are visual thinkers, it is highly likely that the attention of children on the Spectrum can be captured by atypical lighting schemes reviewed (Hernández 2020). Movement, brightness or shimmer and colours are characteristics that toddlers on ASD tend to look for in objects based on the experience of the interviewees, all of these properties are inherent to light.

Besides the positive impact that could have lighting on ASD users, it seems that incorporation of other sensory systems on the practice can enhance the experience of the user. The most preferred by the participants is touch; being a passive sense that requires proximity, the toddler can "choose" to have contact, encouraging in some extent self-confidence on the individual.

"What if light changes when more than two kids are playing together".
(Mesa 2020)

Interaction between light and users was the second most recurrent answer as it can act as a motivation to initiate communication and social interaction (with peers). As simple as triggering changes on light sources when group play happens.

Among life-long abilities that could be developed using atypical lighting schemes as an educational tool participants accentuated the following:

- To encourage and develop joint attention as a pillar for developing communication and social interaction interests. For example, if the support professional captures the attention of the children by triggering a "blob" of light; the professional can use that moment to teach him how to modify the "blob" (position, hue, brightness) by waving its hand on the air. The kid will engage on the task and repeat it, then asks for more. On the example can be understood that users developed joint attention, motor skills and at some extent, communication.
- Communication and social interaction, which includes non-verbal language like pointing to a light source or looking at it when switched off; the toddler is requesting to switch on the light source.
- Routines and predictability in order to promote self-care and independence. For example, a light source changes gradually over time from 100% brightness in the morning to 10% when its time to go home. Learning the meaning of the light dimming will be a process, and eventually association could happen so the toddler would stop asking if he can leave school every hour.
- Sensory play and imagination. By using abstract projections of shapes or colours could help the toddler to imagine that, for example, is on the space.

- Visuospatial comprehension. Depth and volume of shapes at the classroom can be enhanced by using lighting layers.
- Disinhibition. By creating games with no rules, like for example the same "blob" cited, could be transformed by movements or gestures, but there is no specific rule for it, so the kid creates its own game.
- Mathematical logic. Learning simple concepts such as more and less by using the brightness of light sources were dimming is controlled by the support professional or even the kid through an analogical device.

Possible negative impact and considerations to reduce it.

Although interviewees showed very positive about the project and framework, concerns regarding negative impacts of atypical lighting schemes on children on ASD arise being the primary one hyper-sensitivity as it varies from individual to individual in some cases on the same person. Therefore, individualisation, adaptability and regulation are needed.

Based on empirical lighting knowledge, controlling brightness, hue, patterns shifts and even beam angles of light sources is possible (either it is one or one hundred fixtures) trough appropriate lighting control system. Nevertheless, user interface in most of these systems are not "user-friendly" and intuitive to use (in fact, even lighting professionals require of people specialised on this tools when performing commissioning). Hence, this could present a problematic for ASD support professionals when trying to customise or adapt artificial lighting on-demand, and real-time basis. Lighting control systems will be explored in the design phase of this project.

Knowledge of sensory profiles of users could lead to a better experience and improve results when using atypical lighting schemes as a tool. Individualisation and progressive "programs of light" should be designed for each individual as per particular requirements.

As some individuals on the Spectrum present co-occurrent deficits or pathologies such as epilepsy, it is essential to know them before the usage atypical lighting approaches in order to prevent any risk of harm. On the specific case of epilepsy, it is not recommended to expose those individuals to this approach; it represents a high-risk scenario for them.

Interviews closure

As mentioned on the discussion section, seems that artificial lighting awakes interest among the population on ASD, suggesting the possibility to integrate atypical lighting approaches as a pedagogical tool for children on the Spectrum is feasible as long as following matters are considered:

- Interaction between lighting and users should be possible in order to enhance learning experiences. Considering specific needs of toddlers on the Spectrum at some extents this interaction should be tactile as well, allowing the user to "touch" the light or its elements. Hence, the design approach should be from a "material" point of view (tool itself) and "immaterial" approach (light emitted).
- Lighting must be adaptable among users allowing individualisation of "pedagogic programs" or focused learning objectives.
- Personalisation of lighting based on the sensory profiles of the individuals by considering hyper and hypo sensitivity as well as fluctuations between them on the individual.
- Among the different learning areas, lighting should promote joint attention on a fundamental level to build on communication and social interaction skills. From there, more specific objectives can be developed for each kid.
- Introduction to the children on the Spectrum to the tool should be progressive, allowing familiarisation, understanding and adaptability as a part of the process.

These considerations will be part of the design principles at the design phase of the project.

The development of full lighting scheme for ASD classrooms is not the main objective of this project. Nevertheless, this research can be considered as a trigger for future research regarding how light should be designed for learning spaces and possible implications of new lighting technologies among the population on the Spectrum.

Understanding Autism, Conclusions

Incorporation of sensory disorders as a diagnostic criteria of ASD on the DSM-5 (American Psychiatric Association 2013; Hernández 2020) is driving researchers to explore the usage of sensory stimuli during support interventions of individuals on the Spectrum.

As the visual system is the most preserved among the population on the Spectrum (Kana et al. 2006; Gaffrey et al. 2007), is widely accepted that support professionals use visual stimuli as a mechanism to develop communication and social interaction skills while promoting joint attention and adaptative skills among individuals on ASD (Howlin 2005; Lord et al. 2018).

This thesis argues the use of artificial lighting as a tool for support interventions to develop communication and social interaction among children on the Spectrum by considering light as the primary visual stimuli among people. Hence, the research question arises:

> "Can artificial lighting be used as a tool for the development of communication and social interaction abilities among toddlers on Autism Spectrum Disorder".
>
> Project Problem Statement

Literature review and interviews with support professionals reveals that in fact, there is an opportunity to implement artificial lighting as a tool on the educational environment of children on the Spectrum.

In order to promote communication and social interaction among ASD children through artificial lighting, this chapter has:

- Proposed behavioural hypothesis based on the diagnosis criteria established on the DSM-5. These are behaviours expected from children on the Spectrum when exposed to specific visual stimuli produced by light.
- Proposed lighting schemes which can help to toddlers on Autism to cope with the sensory experiences and difficulties exposed by Bogdashina.
- Extracted the prime considerations regarding lighting and interaction expressed by the professionals on Autism interviewed.

Through analysis, correlations between this concepts has been found and, furthermore; the relationships among them can be categorised as direct, indirect and low.

Relationships and categorisation sets the foundations for the design and are translated into design drivers and lighting principles on the development explored in chapter II.

The correlation between the proposed behavioural hypothesis, the proposed lighting schemes and prime considerations expressed by the professionals on ASD is expressed on figure 1.17.; where:

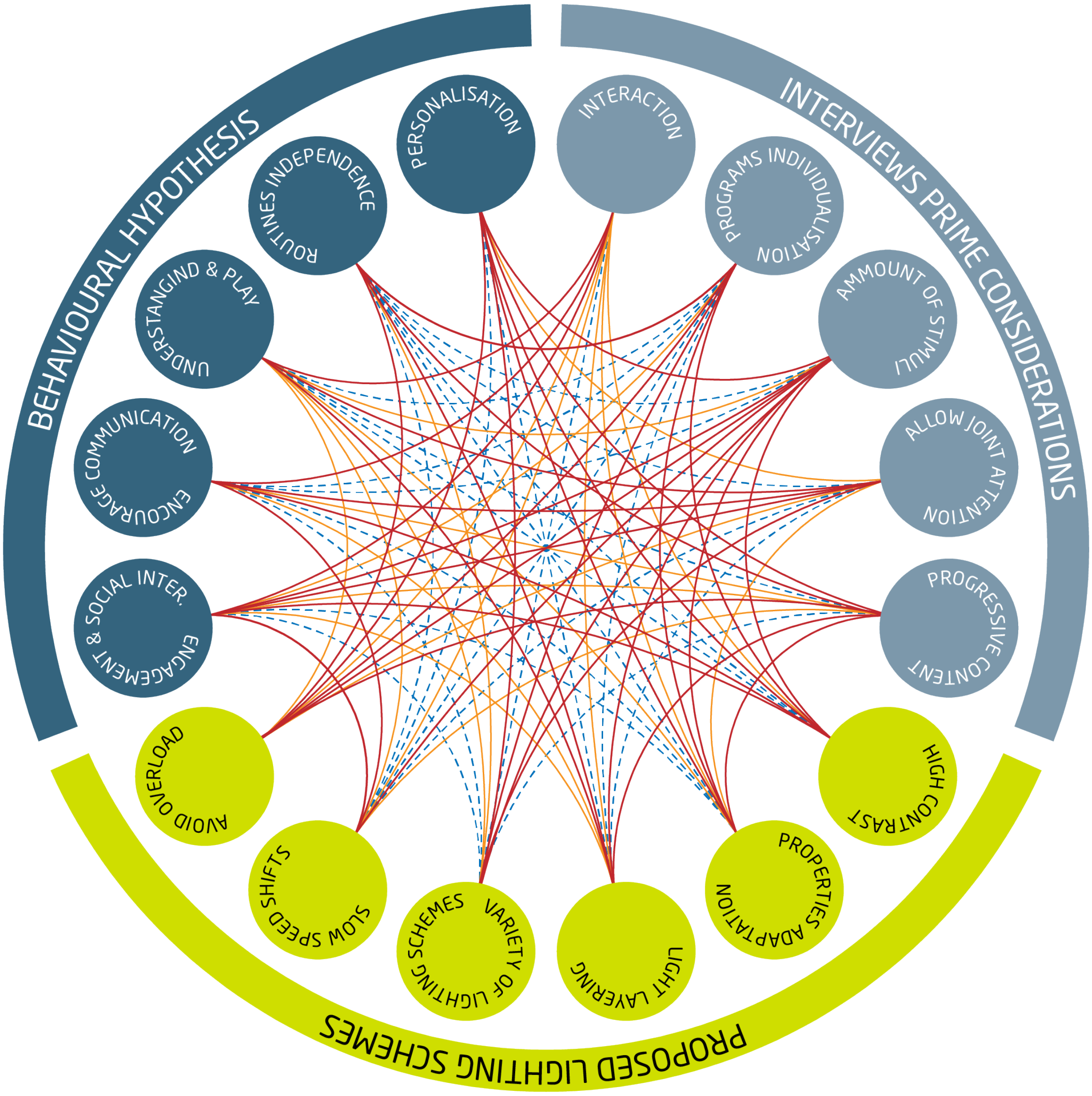
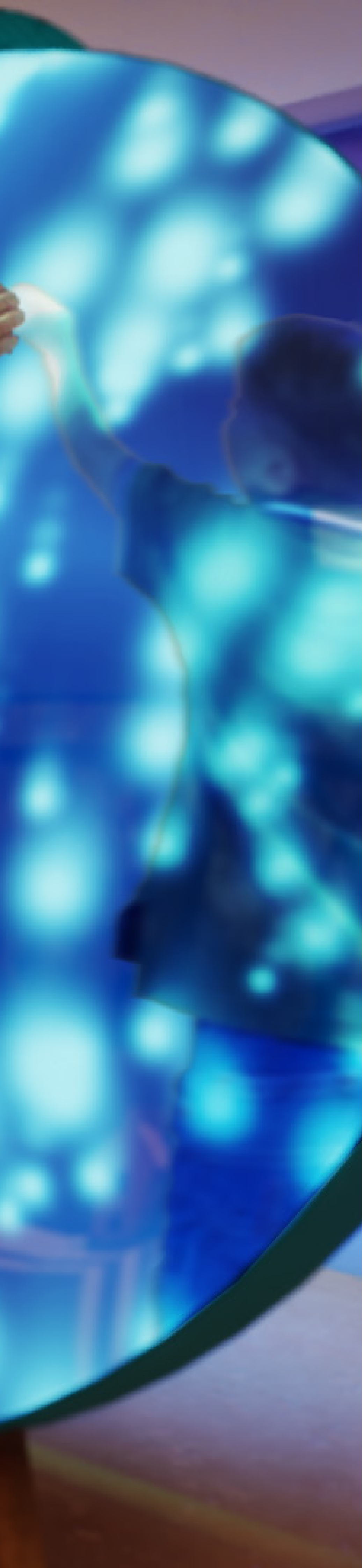


Fig. 1.17. | Relationship between prime lighting considerations expressed by interviewees, behavioural hypothesis and lighting principles, where red lines indicates direct relationship, orange ones, indirect and, blue lines low relationship.

- Red lines indicate direct relationship between the concepts from different perspectives. Therefore, this concepts cant be isolated and is mandatory to address them during the design phase.
- Yellow lines indicate indirect relationship, therefore there is no direct design solution for them as they can be approached from the direct ones.
- Blue lines indicate low relationship. Hence, is not mandatory to approach them on the design phase.

DALIA DESIGN

Fig. 2.1. | Children interacting with DALIA, a dynamic-lighting based tool for the development of lifelong abilities among children on Autism.



As pointed out previously, there is a breach to explore artificial lighting as a mechanism for the development of communication and social interaction skills among children on the Autism Spectrum Disorder.

By considering light as the natural and most apparent stimuli of the visual system; Kana's and Gaffrey's argument that the visual system is the most preserved on individuals on the Spectrum (Kana et al. 2006; Gaffrey et al. 2007); the current usage of visual stimuli as a form of communication among the population on Autism and, the prime considerations expressed by the caregivers interviewed, this chapter proposes the design development of a dynamic-lighting based tool for the development of lifelong abilities of children on the Spectrum as a possible answer to the initial problem statement of this project.

Can artificial lighting be used as a tool for the development of communication and social interaction abilities among toddlers on Autism Spectrum Disorder?

Project problem statement

The design of DALIA (acronym of Dynamic Artificial Lighting In Autism), launches from the hypothesis that its users will be children on the Spectrum from three to 10 years old, as it is suggested to be the best age for individuals on ASD to develop lifelong abilities (Barthélémy et al. 2019). Furthermore, it considers its usage into a scholar context (Salvadó Salvadó et al. 2012) and, supervised by an ASD support professional. Therefore, DALIA acts as a tool for interventions conducted by ASD support professionals and not as an intervention itself.

This chapter argues the design drivers for the development of DALIA (fig. 2.1.), followed by the review of two cases which uses light as a pedagogic tool; afterwards, elaborates on the concept behind the design and introduces the idea of dynamic lighting as a system to achieve the design drivers established.

To conclude, the conceptual design is developed as a technological system from two perspectives: the materiality of the tool (the object and its components) and the immaterial components (artificial dynamic lighting and means to control it).

Design Drivers

Behavioural hypothesis proposed in the Understanding Autism chapter and prime considerations of the interviewees shape the design brief for DALIA. By analysing them relationships between the design brief and the lighting schemes proposed previously, the following design drivers were distilled to outline the backbone of the design development:

Engagement.

To claim the attention and focus of individuals on the Spectrum in order to stimulate their curiosity and to learn as a consequence, beyond merely calling their attention (a loud sound or restricted interests could do it), DALIA must be able to engage users.

Eliasson (2009) argues engagement as the fifth dimension of space (height, length, depth and time the other four), by proposing the concept "YES" (Your Engagement Sequence) as a fundamental element of the perceptual process. Eliasson suggests that "YES" thrives our attention to time movement and changeability in order to create own perspectives of spaces and experiences, that without time, the idea of engagement does not make sense (Eliasson 2009).

Eliasson invites to enhance the role of the observer in art (in this case, learning) as an active participant through engagement, where individuals can create experiences (fig. 2.2.). Hence, long term memories (knowledge) which in this context can be applied in the future.

Under this perspective, DALIA proposes to engage its users by introducing time, movement and participation as variables for change in order to encourage social interaction and communication.

Flexibility.

From the French flexibilité; Latin flexibilitat-em, flexibilis: adj. and n.

"Susceptibility of modification or alteration; capacity for ready adaptation to various purposes or conditions; freedom from stiffness or rigidity" (Oxford English Dictionary 2020).

As Autism is a Spectrum; symptoms, behaviours and cognitive development varies from one individual to another. Therefore, DALIA must provide the possibility of adaptation according to

Fig. 2.2. | People lying on the floor taking a sunbath during the exhibition the Weather Project in 2003. The gigantic artificial sun called people attention to the level of invite them to take a sunbath.

the individual's pedagogic programs. Lighting "effects" should be versatile and easy to adapt for the caregiver.

Besides adaptability of pedagogic programs, DALIA considers the sensory profiles of individuals on the Spectrum. Hence, changes of lighting properties like brightness, movement or colour have to be easily adjustable for different personalities.

Interactivity.

On its article; What Is Interactivity?, Aaron Smuts (2009) analyses different definitions of interactivity and argues that for something to be interactive, its response should be similar to a conversation, where we interact when talking to another person. The response is not fully controllable: the other can respond with a question, an affirmation or a criticism over the same topic.

Smuts suggests that, in order to be interactive "(...), something must be responsive in a way that is neither completely controllable nor completely random" (Smuts 2009, 54).

Fig. 2.3. | People interacting with the footpads on The Pool by Jen Lewin Studio. The footpads reacts to people weight, position and direction of movement with lighting effects.

By providing DALIA interactivity under this approach, it should respond to ASD individuals through lighting in a partial "expected" way, but with some components that could randomise the reaction in order to promote cognitive flexibility, understanding and play.

Interaction can be seen as well as a participatory driver which leads to engagement, therefore enhances experiences among participants.

Although interactivity frames a "digital" experience, proximity would allow for contact and touch experience. Hence, DALIA should allow proximity of the user, to been touch either if DALIA provides a response or not (Gil Morán 2020).

Contextual.

Beyond providing us visibility when it is dark, light provides information such as the time of the day which we can know by observing the size of a shadow or the colour temperature of the sunlight. Tapio Rosenius (2017) argues that artificial lighting allows us to be aware of things without being aware of things.

On the webinar "Let's Move Towards Dynamic Environments", Rosenius (2017) explores the possibilities of lighting to communicate data in a subliminal form; just like the shadows of the sun informs the time of the day, specific patterns or changes in artificial lighting can provide information through the peripheral vision system (Rosenius and Signify Lighting University 2017).

By addressing the pre-cognitive processes, Rosenius argues that communication of the context can be provided to the people without distracting them from main tasks (Rosenius and Signify Lighting University 2017). As reviewed in the previous chapter, individuals on Autism have proved to be efficient when receiving information prior to cognitive processes (Behrmann, Thomas, and Humphreys 2006). Therefore, DALIA should provide contextual information to the users to help them to understand routines, specific events like weather change or playtime, without distracting them from other tasks when it is not necessary.

These design drivers were considered during the design development of DALIA, hence, every design decision made was in favour of these, and the design brief.

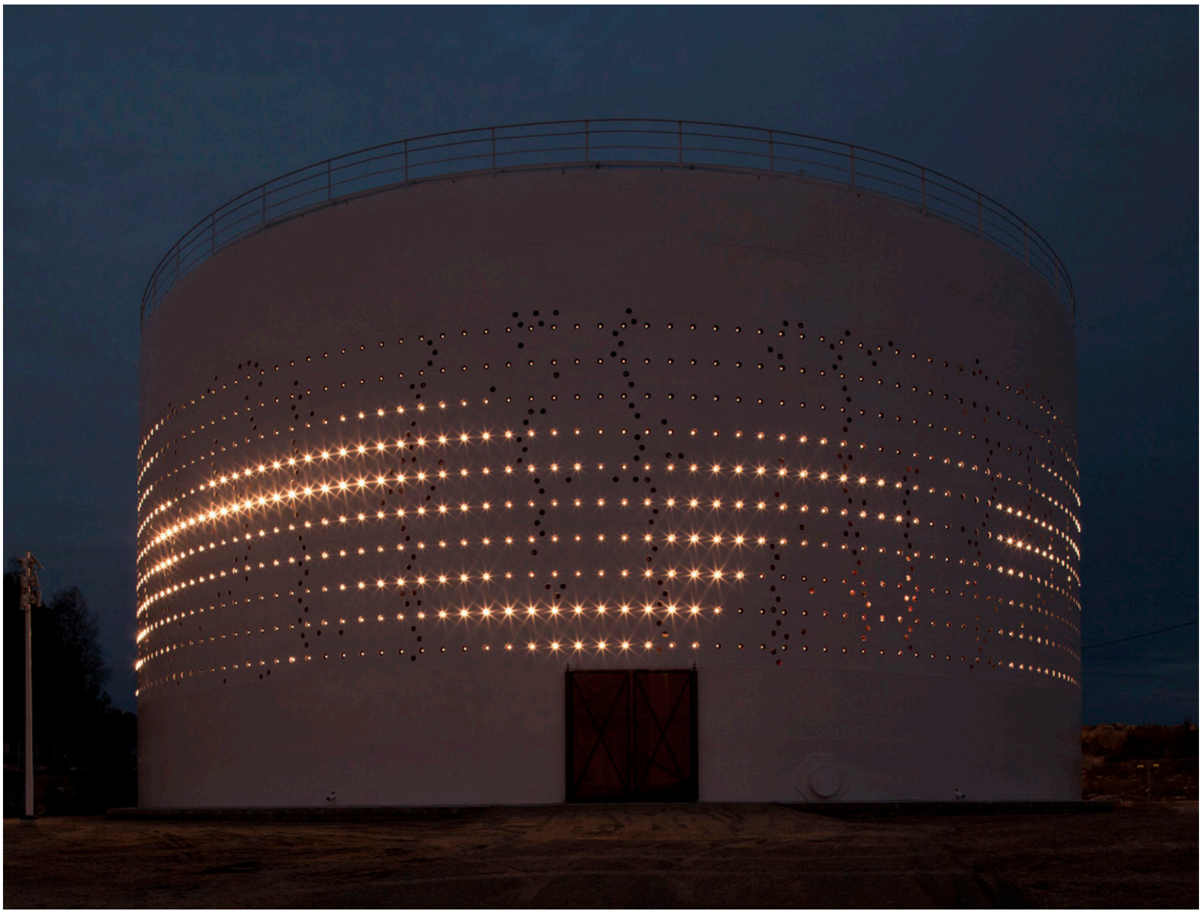


Fig. 2.4. | On the Silo 468 by Lighting Design Collective, lighting "movement" is triggered by context information like weather.

Lighting as a Tool, Cases Review

As pointed out previously, evidence-based data regarding the relationship between lighting and Autism is limited and even more, the usage of lighting as an educational tool on support interventions of individuals on the Spectrum.

Nevertheless, some projects were lighting is used as a tool on the framework of this project were found:

- Lighting table used Montessori educational programs.
- Pictogram Room. Research regarding the usage of interactive technologies for the development of individuals on Autism.
- Snoezelen Room. Organisation which develops multisensory environments for sensorial stimulation.
- Wide range of sensory-based therapies and organisations which offer them.
- Magic Room. Research for the design of spaces to propitiate the development of children with neurodevelopmental disorders (NDD).

Two cases were selected for in-depth studying and understanding, Pictogram Room and Magic Room, as they are evidence-based and holds scientific research to support the proposals and, in some extent, the proposals are linked to the design drivers of this project.

Pictogram Room

Pictogram Room is a research developed by Herrera, Gerardo et al. (2012), Valencia University, Birmingham University, Pompeu Fabra University and Orange Foundation.

This study focuses on the application of "natural-interaction" technologies for the development of body language, joint attention and imitation abilities among the population on the Spectrum. The research team developed a computer-based application, described by them as a "group of educative videogames for children and adults on the Spectrum" (Herrera et al. 2012, 41).

The video games designed are displayed through a video projector on a room (here the lighting component, as a video projector is a hyper-controlled light source) and; with the usage of a depth mapping camera (Kinect) and computer vision algorithms, the user can interact with the images displayed by the projector (fig. 2.5.).

Researchers argue that through the use of visual and sound stimuli and "natural-interaction strategies", the user interacts

Fig. 2.5. | Kid interacting with the images displayed by the projector while using Pictogram Room video-games.

with the video games by using their body, leading to learn and develop abilities such as self-awareness, joint attention and social interaction (Herrera et al. 2012).

The software comprises ten different games, each one with different levels of complexity where the user can move forward along them when developing specific tasks. The games are divided into two families ('Pictogram Room' n.d.):

- The body. Activities based on the movement of parts of the body, touching or following elements of the image projected, self-identification and superposition of real-time images of the user and pictograms (fig. 2.6.).
- Positions. Formed by games involving imitation of body postures, create shapes through body movements, memory of body positions and sequences and interaction of movements and objects projected, like pushing a box through the image (fig. 2.7.).

Pictogram Room is an easy access software that can be downloaded from Pictogram Room website (http://www.pictogramas.org/proom/init.do?method=downloadsTab). Nevertheless, interviews with professionals suggests that it is not popular among the caregivers as only one of the interviewees knew about it.

Although the project presents a solid background for the development of Pictogram Room, it lacks information regarding evidence-based results to confirm the efficacy and effectivity of the program and statistics to measure the progress of the users.

Learnings from Pictogram Room.

- Pictogram Room requires minimum setup to be used on scholar contexts, as the software is downloadable for free and most of the classrooms already have projectors and computers. Hence, acquisition of a depth mapping camera would be the only investment.
- As it can be applied on scholar context, it allows access to it regularly following in this context, the intervention principles regarding intensity and generalisation: systematic manner on a daily basis (Barthélémy et al. 2019; Wing 1981).
- Allows user interaction with visual stimuli through projected light; hence, indirect lighting, reducing the possibility of atypical behaviours due to visual hypersensitivity.
- Usage of self-awareness as a learning frameworks suggest to be effective, during interviews with ASD professionals, it mentioned with regularity by the interviewees.

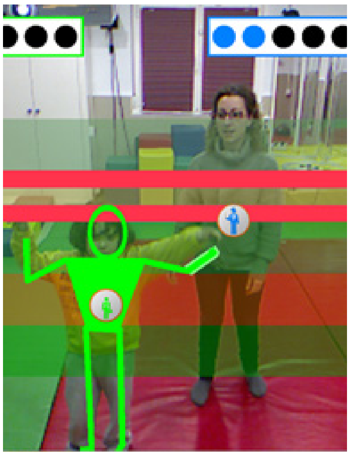


Fig. 2.6. | Kid recognising himself and his body parts through Pictogram Room.

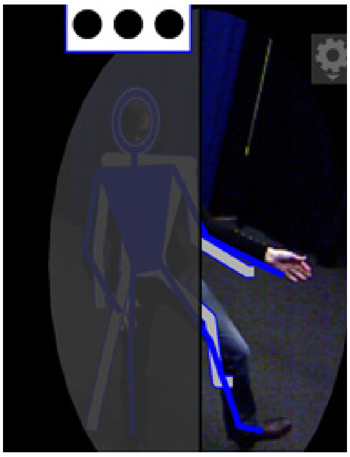


Fig. 2.7. | Person imitating postures displayed by Pictogram Room games.

- Social interaction is limited, as it only happens with the caregiver when playing. Is not mentioned if it can be used by more than one kid allowing social interaction among peers.
- The software is "closed", meaning it does not allows creation or modification on real-time for individualisation of programs (beyond the different levels of complexity within the games).
- As there is no evidence-based results published, it is hard to know if the program is generating an improvement among users.

Magic Room

Magic Room is a project of Franca Garzotto and Mirko Gesolmini from Politecnico di Milano. Authors describe it as a "smart space for use by children with neurodevelopmental disorders (NDD) and their caregivers" (Garzotto and Gelsomini 2018, 38) which allows embodied interaction for the improvement of cognitive process, communication, emotional areas and motor skills among NDD population (being ASD included on this).

Ambient sound, visual projections, soap bubbles, aromas and lighting are used within the space of Magic Room in order to stimulate the vestibular, proprioceptive and tactile sensory systems among users as shown in figure 2.8. (Garzotto and Gelsomini 2018).

On their article Magic Room: A Smart Space for Children with Neurodevelopmental Disorder, Garzotto and Gesolmini (2018) argues the usage of the room by NDD users for three months can lead to an improvement on cognitive process, communication, emotional areas and motor skills.

In order to design the space elements and interaction algorithms, the researchers held three workshops with caregivers and individuals with neurodevelopmental disorders. The methods used during the workshops were free-play and interaction, structured games and, a mix of both schemes in order to explore the possibilities and proper approaches for the users and design the test method.

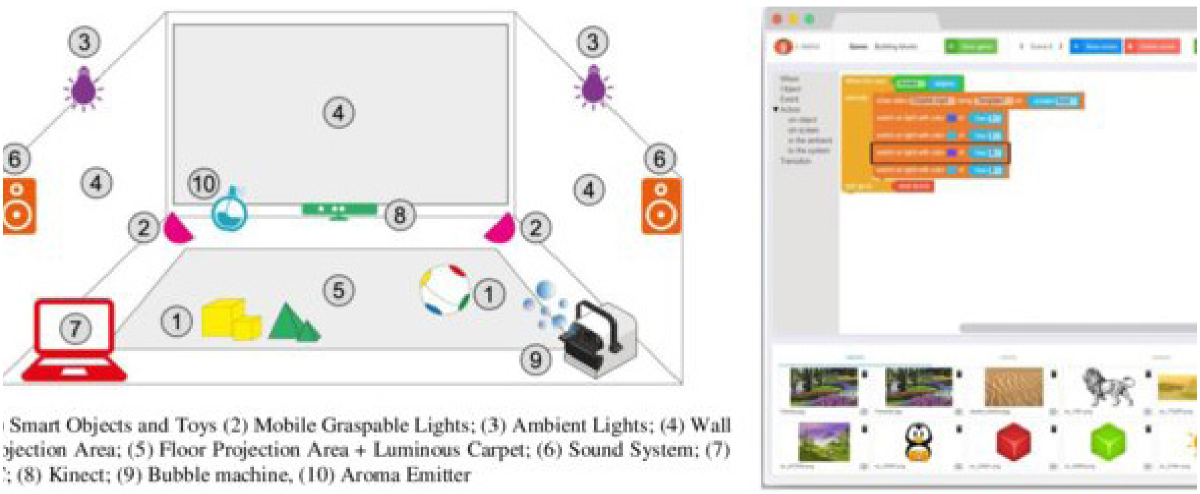


Fig. 2.8. | Arrangement of sensory devices along Magic Room.

"Lights on the carpet, mobile lights and bubbles attracted the immediate attention of all subjects, suggesting that these stimuli might be particularly engaging for children with NDD".
(Garzotto and Gelsomini 2018, 43)

Exploratory study of the Magic Room was held after the workshops, with a total of 19 children with NDD as participants and caregivers. The study duration was of 3 months on a two-week assistance basis (6 visits total) with an average duration per visit of 39 minutes. The participants assisted in the room divided in 4 groups with two caregivers per group.

Caregivers filled observation reports for each child after each visit to report qualitative progress on specific therapeutic goals.

Observations report analysis suggests an improvement in the cognitive areas, communication, emotional areas and motor skills of the participants; being the most relevant on the cognitive area where the scores of the last session double the initial ones in some groups.

Learnings from Magic Room.

- Observations from the caregivers regarding lighting, suggests the hypothesis presented previously about the usage of lighting as an engagement tool, to be true.
- Implementation of this scheme of rooms into a scholar context might be complicated as it requires adaptation of a full space.
- As part of the project includes an interface for control, it allows adaptation and personalisation of programs for specific individuals.
- The space, interactions and general scheme of usage, promotes communication and social interaction between peers and also with caregivers.
- Participatory games propitiate social interaction.
- It allows a progressive introduction of the features to the users like increasing brightness of lighting fixtures gradually from the beginning of the intervention and interaction elements are added progressively.

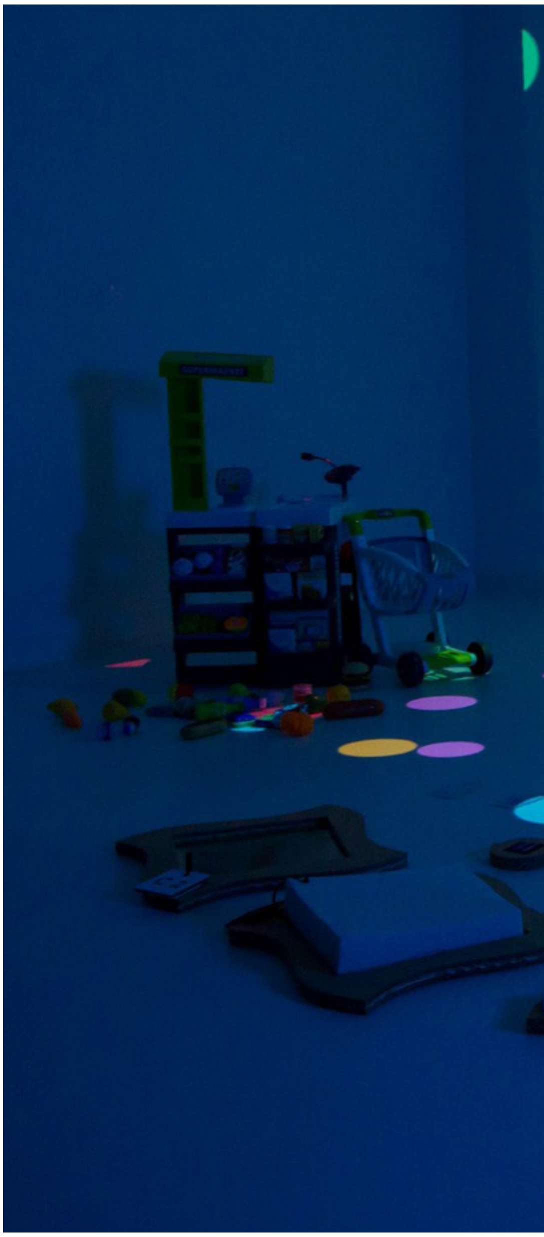


Fig. 2.9. | Picture of Magika-Ludomi, the evolution of the Magic Room.

- Although the structure for interventions suggested on "daily basis" by Barthélémy (2019) and Wing (1981) is not followed, participants showed improvements in different areas.
- Some participants presented sensory overload and atypical behaviours as a response, suggesting that the usage of several stimuli at the same time can be risky.

The Concept Behind: A System

Lou Michel (1996) argues that the concept behind a building is more than just a "good idea"; the concept grants to the building a reason "to exist" and, beyond functionality, gives a meaning, not only to the object, but also for its contents: people.

"Concept is the raison d 'être of a building, the purposes for which it is to be built, including any symbolic content it is to contain".
(Michel 1996, 243)

Meaning shapes objects and spaces; just like sensory experiences shapes people behaviours and personality.

On this extent, this section argues the vision of DALIA as a digital system which integrates the physical and digital "worlds", establishes the lighting principles to follow on the design development and symbolisms in order to provide DALIA of meaning.

Digital system

"In architecture, dynamic luminous embellishments of façades, combined with digital light-control systems, have transcended the conventions and artistic limitations of physical buildings. Many media façades seem to envelop the architecture like luminous wallpaper, suggesting a new type of architecture – the building as a software-adjustable light ornament." (Schielke 2015, 97).

On his essay, Transforming Luminous Pixels into Brand Experiences, Thomas Schielke (2015) argues that nowadays, lighting technologies offer possibilities to architecture to become a "(..) luminous storytelling (..)" after twilight (Schielke 2015, 96). Schielke, addresses lighting as a resource for companies to express dreams, associations, atmospheres, experiences and narratives; that is, meaning.

Although Schielke suggests these concepts under a branding framework for companies, he suggests the integration of digital-lighting and architecture into a single "system", referring to it as Dynamic Lighting and, addresses that without this system, strong storytelling would not be possible. Therefore, artificial lighting is not anymore an additional element in architecture; it becomes part of the architecture and its design process, which adds value and meaning after sunset.

"(...) Think about the role of lighting or the role of digital integration in the project; Why was it there?, What is it there for?. Lighting is still seen as a very sort of technical discipline. It has a sort of very basic functions that are expected to be fulfilled; which is fine but lighting, can be so much more (...)".
(Rosenius and Signify Lighting University 2017)

By changing colours, displaying patterns along thousands of pixels, shifting brightness and hyper-controlled flickering of light sources, Dynamic Artificial Lighting allows modifications of spaces without modifying the space, generating tension and attention of the users. Hence, it provides a focal point in the environment, propitiating memory on a pre-cognitive level (Rosenius and Signify Lighting University 2017).

Even though authors refer to Dynamic Lighting on the architectural framework and urban environment, this thesis proposes its application into a smaller scale and, in scholar context. In order to accomplish the design drivers and goals of the project, lighting principles proposed should be seen as a system which integrates both physical and digital contexts through Dynamic Artificial Lighting. Hence, a system: Dynamic Artificial Lighting In Autism or, DALIA.

DALIA system is comprised of three elements: First, the container (the object) which conforms the "body" of DALIA, secondly, the light sources and means to control them (DALIA's brain and organs). Lastly, the "digital content"; which shapes de behaviour of the Artificial Dynamic Lighting and shapes DALIA's personality.

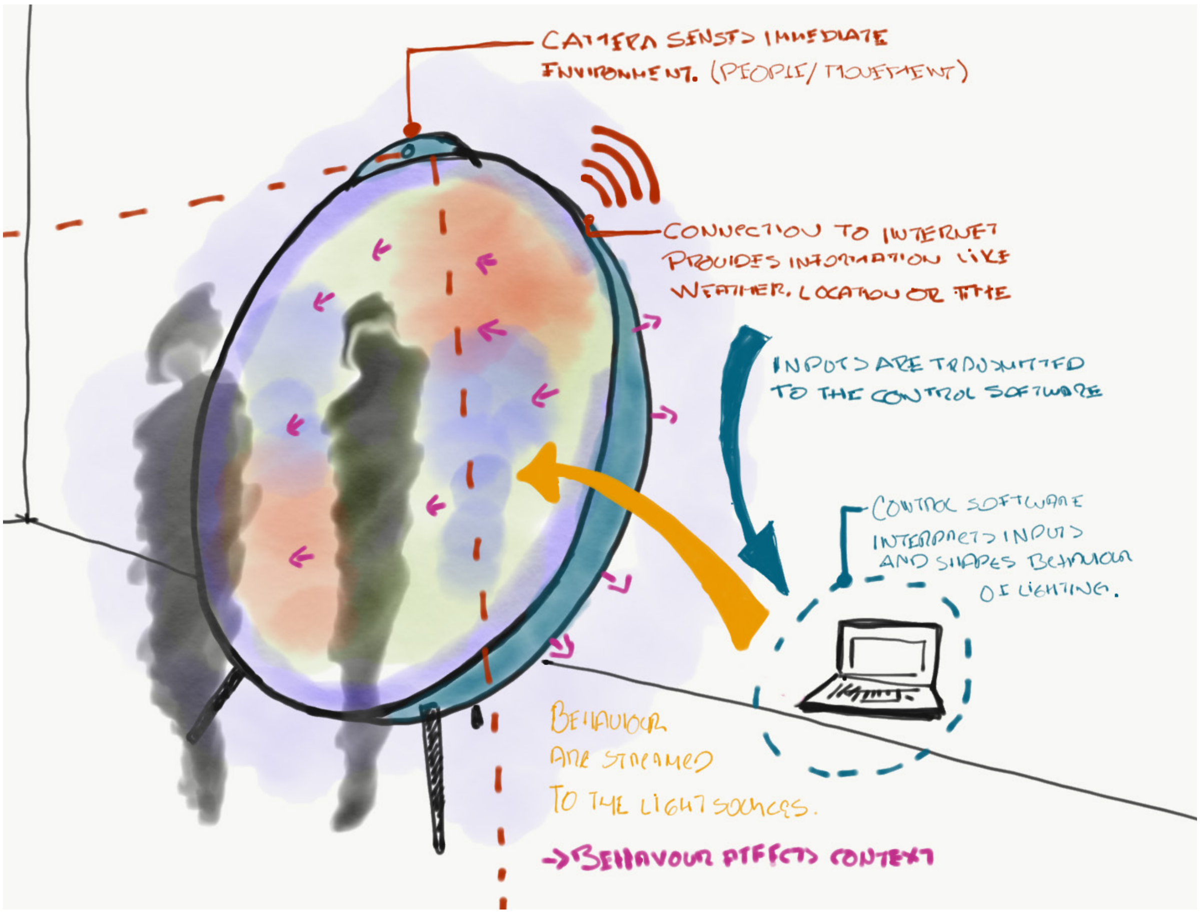


Fig. 2.10. | Conceptual sketch of DALIA as a system.

Lighting principles

In order to achieve the design drivers from the lighting point of view, the following principles must be present on DALIA:

Layering.

By providing layers of light, DALIA will help to understand individuals on ASD spatial perception and "break down" information into pieces, to separate background information from what is important at a specific moment. Layering provides legibility on the space.

Contrast.

High contrast will reinforce the engagement of the user; as ASD individuals respond positively to high-contrast, this will be considered in two aspects:

- Contrast relationship between DALIA and the spaces that contain it (classroom), therefore luminance on main surfaces of the space has to be considered in order to achieve this. DALIA should be "bright" enough to be visible even during daylight at a shadow space.
- Contrast relationship in along DALIA lighting layers, based on the control system, this will be locally regulated to achieve the relationship required on each specific situation.

Brightness & Colour.

DALIA should provide proper regulation of brightness (luminance & iluminance) and flexibility to adapt to the different sensory profiles of the users.

Besides the adaptation of luminances, the literature reviewed suggests that direct lighting or the possibility of visualising the light sources has a negative impact on individuals on ASD (Colman et al. 1976). Therefore, DALIA will recur to indirect lighting effects and diffused lighting and use of colours as a contrast and engagement resource.

Symbolism.

Fig. 2.11. | Symbol of a puzzle piece which used to represent the Autism.

The first symbol created for Autism was the "puzzle piece" (fig. 2.11.) created by Gerald Gasson and adopted on the National Autistic society in 1963 (UK), the belief that people on the Spectrum suffered from a "puzzling" condition was the origin for this symbol; which nowadays is, in general, rejected by the population on ASD. Rejection of this symbol lies in the arguments of exclusion: "People, not puzzles", "I am not a missing piece" (Crosman 2019).

In 1998, Judy Singer coined the term Neurodiversity on her thesis in sociology, where she states "Neurodiversity may be every bit as crucial for the human race as biodiversity is for life in general. Who can say what for of wiring will prove best at any given moment? Cybernetics and computer culture, for example, may favour a somewhat autistic cast of mind" (Spectrum Suite 2020).

Society accepted the term Neurodiversity, and in order to symbolise it, created the rainbow-coloured infinity symbol (fig. 2.12.) to represent Autism. Currently, this symbol, together with the colour light blue, are widely accepted by the population on the Spectrum, and they are worldwide known.

Every year on April 2nd, the world celebrates the World Autism Awareness Day and, during 2019, Autism Europe used the coloured infinity symbol as a flagship for the campaign.

"The rainbow-coloured symbol represents the diversity of the autism spectrum as well as the greater neurodiversity movement" (Wikipedia 2020).

An analogy of the infinity symbol has been used to shape DALIA's "body" as it is explained in figure 2.13. By abstracting the fundamental shape of the infinity symbol, which, can be understood as an "8" placed horizontally, or two tangent circles, DALIA finds its basic form on the most fundamental and straightforward level.

The rainbow-colours, will be displayed by DALIA through light. Besides diversity on the colours, also represents diversity understood as movements of light and flexibility for the users.

Last analogy of DALIA, refers to one of the main motivations of this thesis, which is to generate social value by inclusion. Therefore, DALIA looks to propitiate the inclusion of individuals on the Spectrum by providing them with abilities that could lead them to a better quality of life.

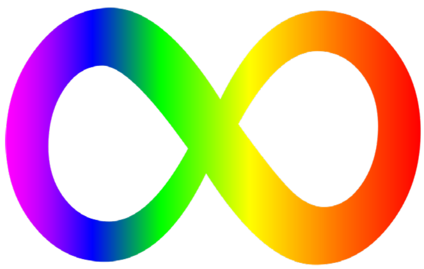


Fig. 2.12. | Rainbow-coloured infinity symbol which currently represents the population on Autism.

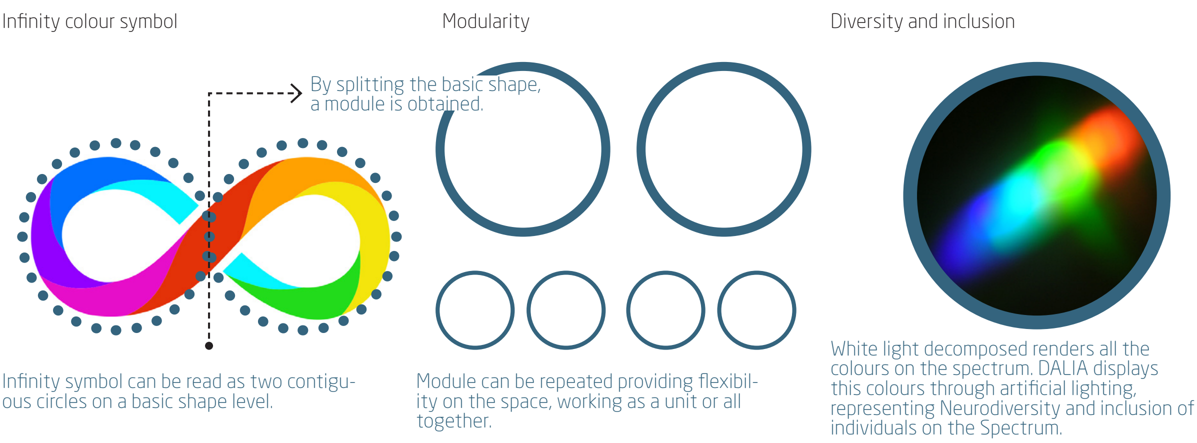


Fig. 2.13. | Analogy of the rainbow-coloured symbol to shape DALIA.

Design Development

The space

DALIA intends to operate during daytime hours and into scholar context (classrooms or designated spaces for ASD interventions). Hence, understanding the lighting and environment conditions was essential as DALIA's prime element is reflected light which, should be visible under the conditions mentioned and bright enough to contrast with the incident light on the surfaces of the space.

The variety of scholar spaces in terms of size, orientation, finishings and lighting conditions is not constant, so it was challenging to designate a specific space with "universal" characteristics. Nevertheless, one of the caregivers interviewed provided information about the space in which she performs activities with children on the Spectrum, so this space was taken as case to review the lighting conditions on it.

Natural and artificial lighting conditions of the space were evaluated through software analysis in order to understand the luminance on the main surfaces of the space.

Physical characteristics of the space.

The room is located at a scholar centre in Madrid, Spain. The centre has three buildings of two levels each, the arrangement of the buildings is in "n" shape in floorplan, as can be seen in figure 2.14. The space analysed is on the ground floor of the west building, with a window oriented to the east.

Interior of the space is an open plan of approximately 6,.30m x 10,20m and 3,20 meters height from finished floor level to ceiling. It has a window of 7,95m length per 2,10m height with a sill height of 1,10m (fig. 2.15.).

Finishings on walls are a roughcast plastering skirting of 1,10m height painted in purple, and the rest of the height painted in white. On the floor, polished red terrazzo and in the ceiling, modular panels of 60 x 60cm painted in white. All the finishings present a worn degree due to usage.

Natural lighting enters through the window on the east wall and, 12 luminaires reinforce the lighting on the space. The luminaires are conventional fixtures or 60 x 60cm to fit on the ceiling grid with four fluorescent lamps as light sources each (fig. 2.16.).

Digital model for analysis.

To analyse the incidence of natural and artificial lighting on the space; a digital model of the room was built on the lighting calculation software Dialux EVO 9.0. The model matches the loca-

Fig. 2.14. | Scholar centre in Madrid.
(a) Top view of the building, "n" shape floorplan.
(b) Perspective view of the centre, red lines indicate the location of the classroom to study.

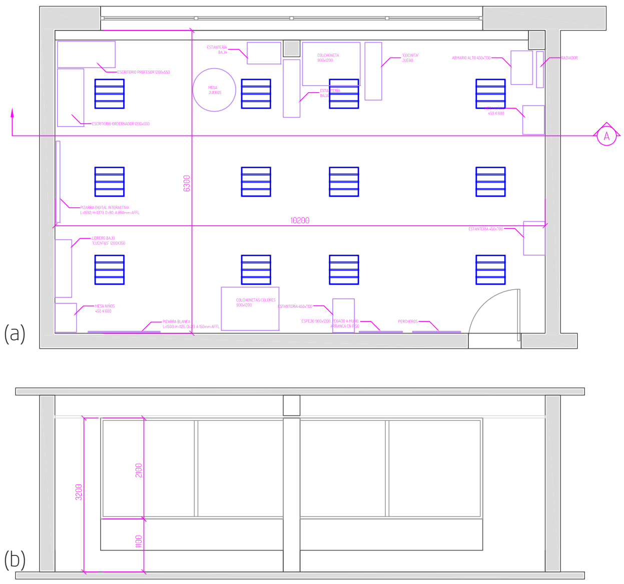


Fig. 2.15. | Dimensions of the classroom.
(a) Floorplan of the classroom.
(b) Section view "A" of the space.

Fig. 2.16. | Picture of the interior room were finishings on surfaces and fluorescent luminaires can be observed.

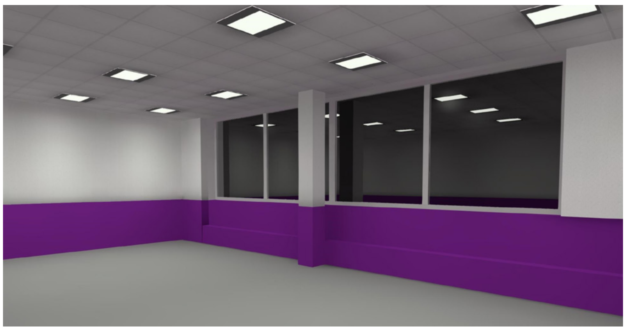


Fig. 2.17. | Computer generated image of the digital model created for the lighting calculations.

tion and north orientation of the real room for daylight calculations. Finishings of walls, floor and ceiling where mimic on the software and the following reflection factors where applied (fig. 2.17.):

- Walls; purple skirting, Colour material RGB (117/36/139), material painted. Reflection factor of 9% and reflective coating 0%.
- Walls; rest of height. Roughcast plastering white, provided by the software. Reflection factor of 84% and reflective coating 0%.
- Ceiling; Panels of 60x60cm, white, provided by the software. Reflection factor of 70% and a reflective coating of 0%.
- Floor; sandstone material provided by the software. Reflection factor of 31% and 0% of reflective coating.
- Windows; Transparent material provided by the software. Reflection factor of 10%, transmission of 90% and a refractive index of 1,50%.

Luminaires on the ceiling were mimic by using a photometric file similar to the actual fittings; each photometric file provides 3855lm, 3259K and symmetrical distribution of light of approximately 90°. A total of 12 luminaires were placed in the model on the location referenced by the interviewee.

Daylight and artificial lighting incidence.

Through a simple analysis of window orientation and sun movement, it was determined that the area with less daylight incidence is the south-west area of the room. Therefore, deep analysis of sunlight incidence was carried out on this zone (fig. 2.18.).

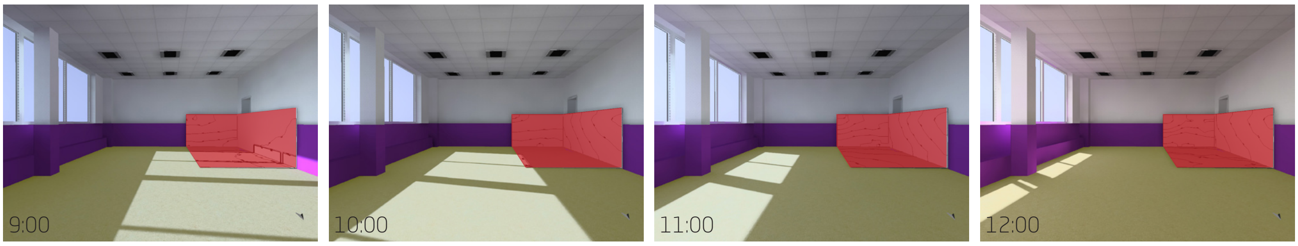


Fig. 2.18. | CGI of the sunlight incidence on the interior of the room from 9:00 to 12:00 during summer solstice (June 21st). Area with less daylight incidence is highlighted in red.

As DALIA should contrast from the background surfaces (walls and floor), three calculation surfaces were created on the digital model in order to obtain luminance (cd/m^2) values on those surfaces (marked in red on figure 2.18.). Calculations of daylight and artificial lighting were run separately. For the daylight incidence, the calculations were developed based on the hours of class (9:00 to 16:00), and one calculation per hour was done on the four main dates of solar incidence (equinoxes and solstices).

In order to obtain the average and maximum luminance levels provided by daylight on the calculations surfaces, a total of 64 calculations were practised in two series.

- The first series (32 calculations), assuming that the finishing of calculation surfaces is roughcast plastering white, with a reflection factor of 84% (fig. 2.19.a and 2.20.).
- The second (32 calculations), assuming that the finishing of calculation surfaces is roughcast plastering painted in purple, with a reflection factor of 9% (fig. 2.19.b and 2.21.).

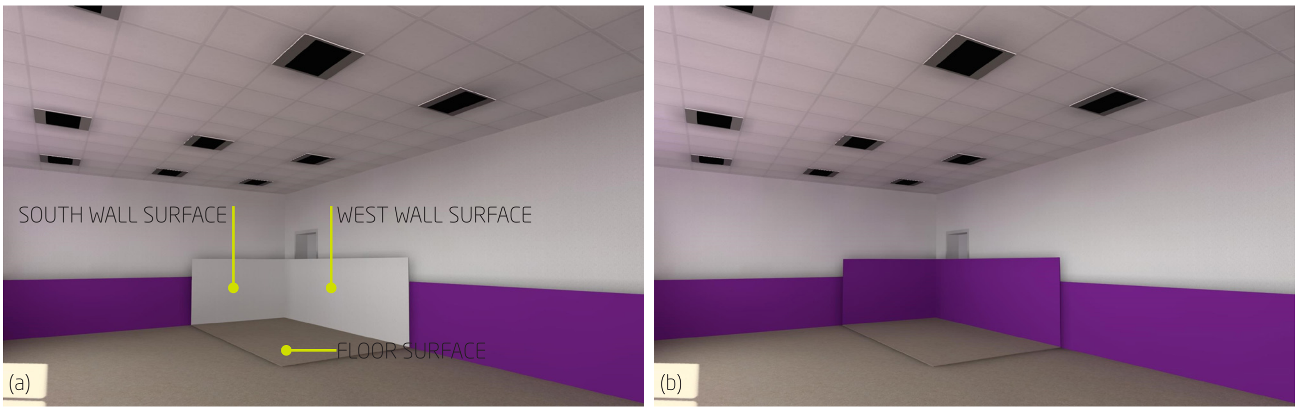


Fig. 2.19. | Calculations surfaces with different finishings for luminance calculations. (a) Roughcast plastering white painted. (b) Roughcast plastering purple painted.

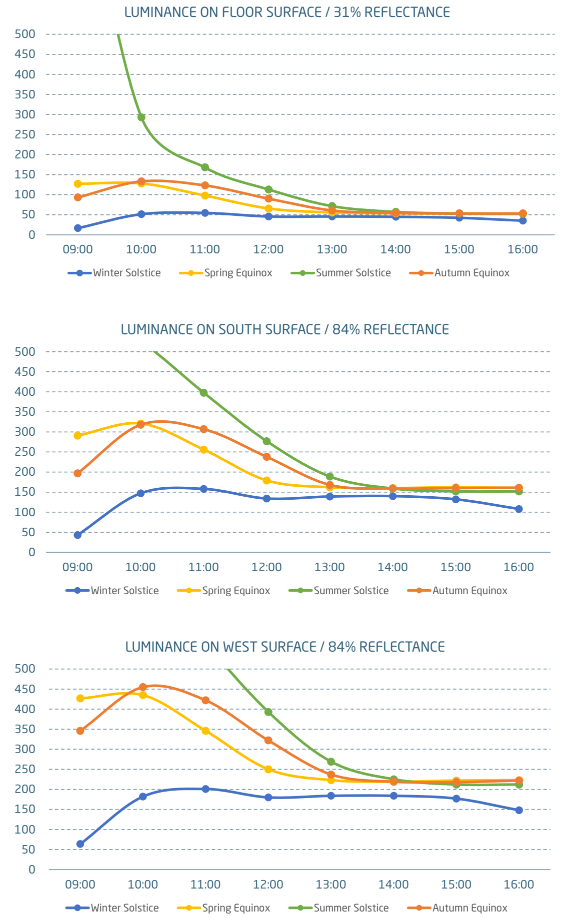


Fig. 2.20. | Luminance values obtained from incident daylight on calculation surfaces with roughcast plastering, white painted.

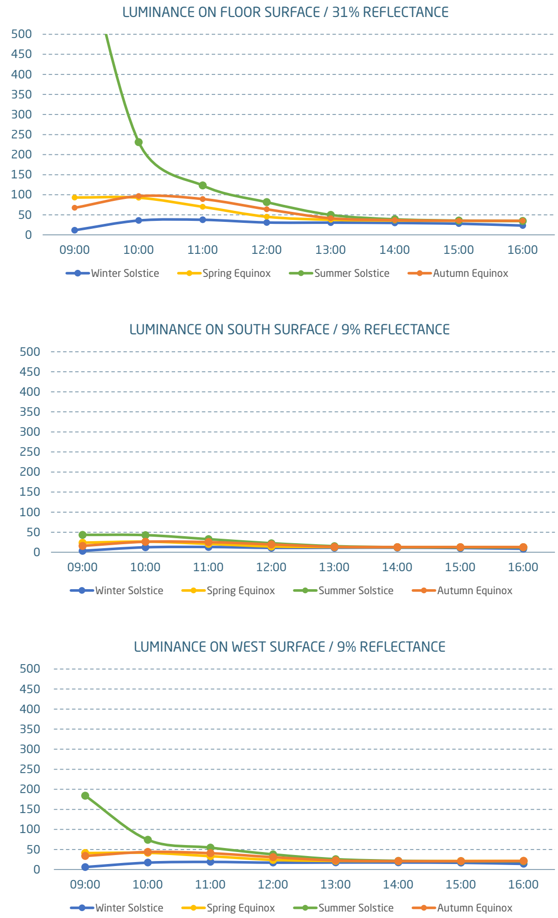


Fig. 2.21. | Luminance values obtained from incident daylight on calculation surfaces with roughcast plastering, purple painted.

Calculations provided a total of 192 values for analysis (8 hours x 4 dates x 3 surfaces x 2 finishings). Results show that yearly average luminance of the floor is 93 cd/m^2, for the south wall is 116cd/m^2 and 182cd/m^2 on the west wall.

Maximum luminances are achieved during the summer solstice (June 21) at 9:00 a.m. when the calculation surfaces were with the roughcast plastering white finishing, being these 965cd/m^2 in the floor, 609cd/m^2 at the south wall and 1,872cd/m^2 on the west wall.

For the artificial lighting, a single calculation was carried out, as it is assumed that the artificial lighting provides a constant output over the different dates and times. For the calculation, it was considered the fittings are working at 100% (as fluorescent fixtures cannot be dimmed), with a maintenance factor of 80%.

Results show that artificial lighting adds 51cd/m^2 on the floor, 80cd/m^2 on the south wall and 72cd/m^2 on the west wall. Therefore, daylight is predominant on the space.

Background luminance & contrast ratio.

DALIA should provide enough brightness in order to contrast with the background and be visible during the daytime.

Based on the analysis carried out; yearly average luminance of the main surfaces is considered as the background for DALIA. Although the breach between average and maximum luminance values of the surfaces is high, maximum values are not constant (they only happen on a specific hour and specific date). Therefore the background values considered are as follows:

	Yearly Minimum	Yearly Average	Yearly Maximum
Floor surface	12 cd/m^2	93 cd/m^2	965 cd/m^2
South Wall surface	4 cd/m^2	116 cd/m^2	609 cd/m^2
West Wall surface	6 cd/m^2	182 cd/m^2	1,872 cd/m^2

From the average values, the highest is 182cd/m^2, so this is the base value to consider for DALIA's background.

Studies suggest that the human eye, in order to detect contrast between an object and its background, the ratio should be 8,9:1. (Michel 1996, 33). Meaning that the object should be 8,9 times brighter than its background.

As children on the Spectrum present difficulties on the perception of scenes, they require higher ratios than neurotypical individuals in order to perceive the objects from their background. Therefore, it is proposed that the contrast between DALIA and its background to be at least a ratio of 20:1.

Hence, brightness emitted by DALIA should be at least of 3,640cd/m^2 (20 times 182cd/m^2), which is two times more than the peak brightness produced by a 4K TV.

Nevertheless, brightness will be controllable in order to adapt it to the different sensory profiles of the users.

(a)

Position Number	Background Luminance (cd/ft^2)	Ratio of Interior Square to Background
1 (black)	4.68	8.9 : 1
2	15.87	2.63 : 1
3	27.02	1.54 : 1
4 (middle gray)	41.7	1 : 1
5	64.46	.65 : 1
6	88.58	.47 : 1
7 (white)	113.0	.37 : 1

(b)

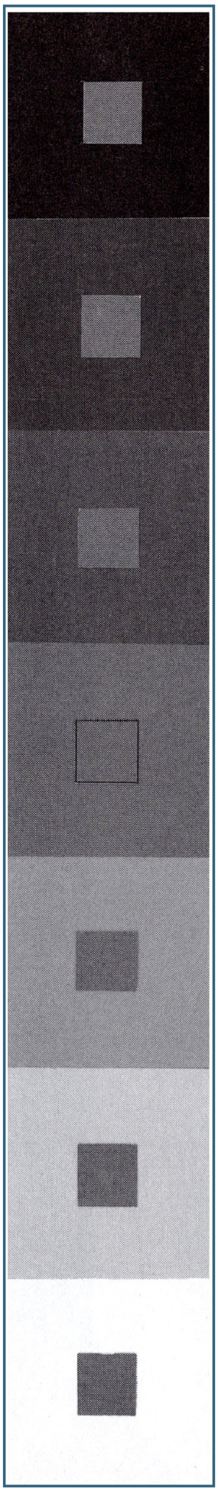


Fig. 2.22. | Luminance ratios (a) and brightness as a function of background (b). Reprinted (Michel 1996, 14, 33)

Sizing DALIA

DALIA users will be toddlers on the Spectrum between three and ten years old. To enhance familiarity, sense of scale and proximity of the users with DALIA; basic anthropometry of the children has been considered for the definition of size and proportions of DALIA.

Size of DALIA has been determined considering three heights among children:

- Mean minimum height on three years old toddlers: 978mm
- Mean maximum height on six years old children: 1184mm
- Mean maximum height on ten years old: 1415mm

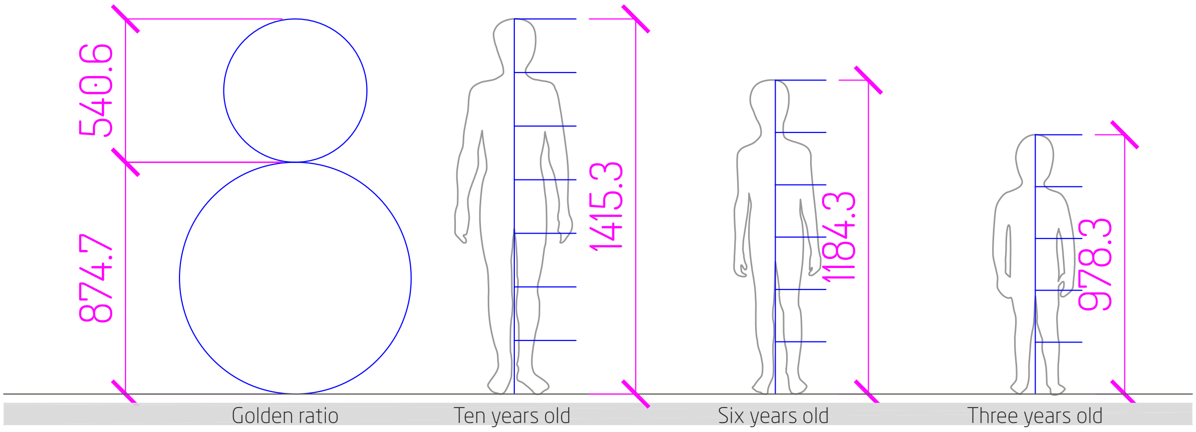


Fig. 2.23. | Heights of children from three to ten years old and golden ratio.

These heights have been obtained by analysing children anthropometry data recorded by researchers (Lueder and Rice 2008, 60–64).

In order to cover the full range of ages that could interact with DALIA, the most significant height has been considered as the base unit for defining the diameter of DALIA.

A circumference of 874,66mm results from applying the "golden ratio" (0,618) to the base height (1415mm) as is shown on figure 2.23.

This size will allow some "portability" and flexibility to accommodate DALIA into a wide range of spaces, or having more than one. For the younger children, the diameter is enough to be used by two persons at the same time, allowing and promoting social interaction as on figure 2.24.

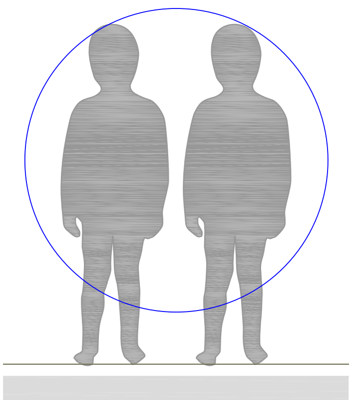


Fig. 2.24. | Proportion of DALIA over 3 year old children.

The design proposes to set DALIA on a vertical plane or "standing" as it is a straight forward position for visibility and interaction for the users. Children run, jump, play and observe most of the time while standing (personal observation), so this position seems to be the right one for DALIA.

DALIA's body is tilted 15° to backwards in order to bring stability to the device and also, to generate a welcome feeling, straight position can be perceived as a "wall" or a limit; by tilting DALIA, the design aims to promote proximity and allow touch (fig. 2.25.).

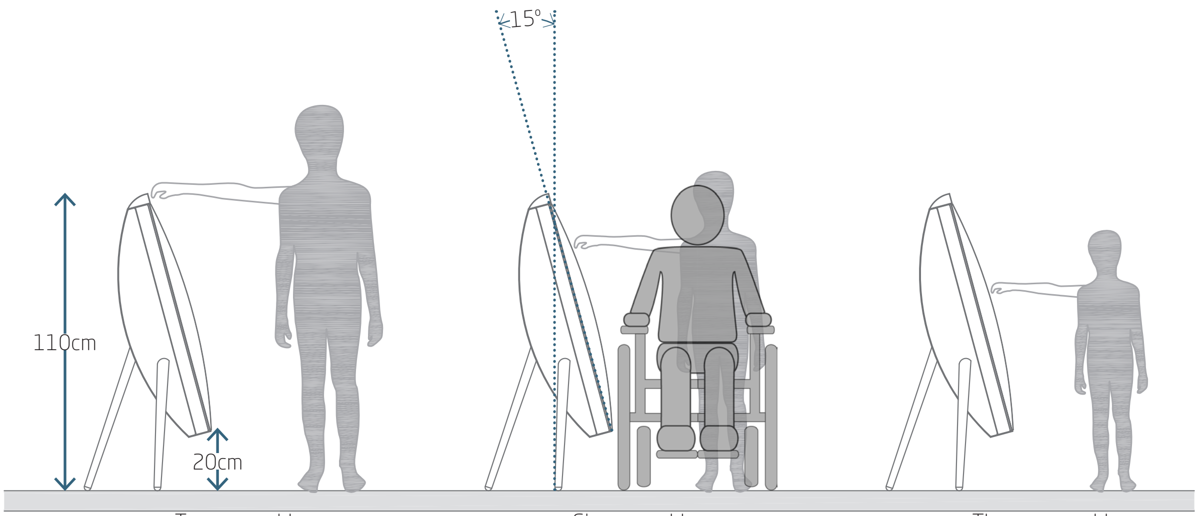


Fig. 2.25. | Position and proportions of DALIA among three, six and 10 years old children.

Lighting layers

DALIA design proposes two lighting layers in order to contribute to the design drivers proposed and the achievement of the behavioural hypothesis (fig. 2.26.).

Both layers operate in a synchronised manner to generate the idea that not only DALIA is affected by its context, but the device itself affects and replies to the environment in order to reinforce the fragmented perception difficulties of children on the Spectrum.

In all layers, dynamic artificial lighting is applied through the control system and the hardware characteristics.

Diffused light.

The first layer is diffused light emitted by the front face of DALIA. Light is emitted by an array of LED light-sources embedded within the hardware of the device. Light hits a diffuser and makes it visible for the users.

The light displayed by this layer is where the users will perceive the dynamic artificial lighting effects, movement, changes in brightness and colour; allowing a direct relationship and interaction between the light displayed and individuals on the Spectrum.

The array of lighting sources of this layer allows subdivision as each LED is controlled independently. Hence, flexibility to display different effects (digital content) among the same layer is possible, contributing to the creation of "virtual layers" along the same physical one.

Reflected light.

The light emitted from the back of DALIA is reflected on the background surfaces behind the device (the space). The light is emitted by a circular array of LED light-sources located at the back perimeter of DALIA's hardware.

By projecting light to the surfaces around the device, this layer allows to extend the influence of DALIA within the space that contains it. Hence, no additional light sources needs to be installed in order to create a contextual environment for the device.

Although this is not the principal lighting layer, it provides the flexibility to increase or reduce contrast of DALIA against its background and contributes to engagement of users by affecting their space (classroom).

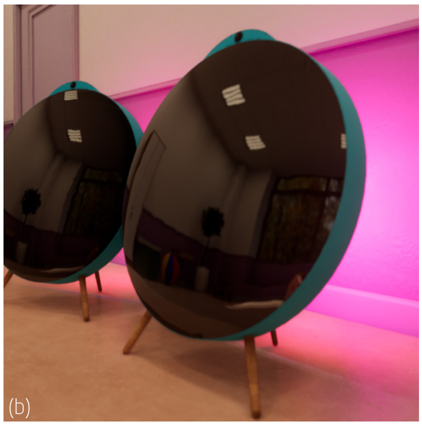


Fig. 2.26. | DALIA light layers. (a) Diffused light layer. (b) Reflected light layer

Fig. 2.27. | Diffused and reflected light layers of DALIA

DALIA's body hardware.

On an essential level, DALIA can be understood as a light-box which emits light in two directions (front and back). A series of layers have been added to this fundamental idea in order to fulfil the concerns expressed by the caregivers interviewed; the behavioural hypothesis proposed and the design drivers and lighting principles of the project. Figure 2.28. illustrates the layers which conforms DALIA body and hardware:

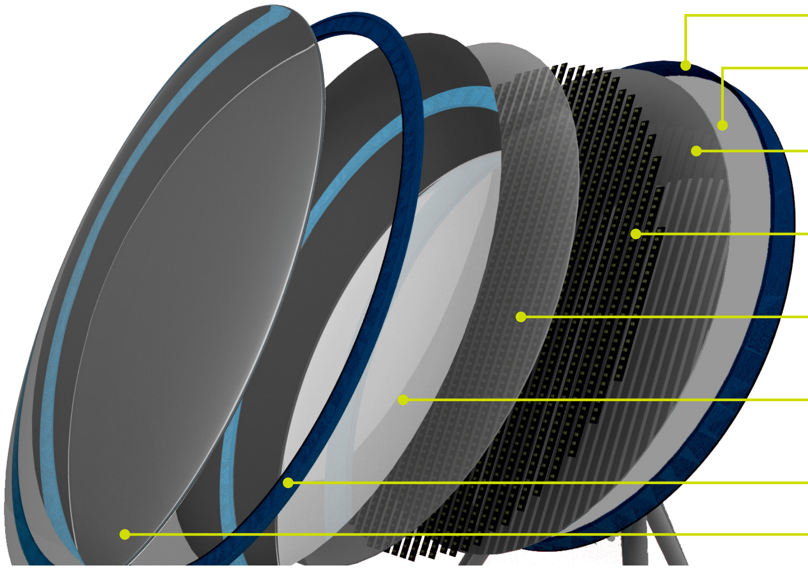


Fig. 2.28. | Body hardware components of DALIA

Transparent cover.

Together with the main body conforms the outer core of DALIA. It can be seen as the skin of the device. It allows visibility of the emitted light, can be touched by the users and in order to contribute to engagement and proximity, it is a writable surface in which users will be allowed to write or draw leading to some sort of personalisation and familiarity.

The material proposed is a thermoformed transparent resin with the following characteristics:

- 3mm thickness.
- 1.49 D542 refractive index.
- 92% light transmission

*Spec sheet of the material can be found on the annexes of this document (resins).

Cover reception ring.

Bespoke aluminium piece to receive the transparent cover and fix it to the main body of DALIA.

Mirror foil.

Is not accessible to the user as it is allocated at the interior of the device attached to the opal light diffuser. Imitates the Gessel camera allowing the user to view its reflection on DALIA (following the Pictogram Room ideas about self-awareness). When DALIA is not emitting light, the reflection of the user and the space is full; when the device is emitting light, reflection is partial.

The material proposed is a reflective solar foil with the following characteristics:

- 4 microns thickness.
- 41% one direction reflectance.
- 88% light transmission.

*Spec sheet of the material can be found on the annexes of this document (mirror foil).

Opal light diffuser.

As the mirror foil, is not accessible to the user. This layer diffuses the light received from the light sources. It will prevent the visibility of the light sources or “dots” and also create smoothness on the light movements and certain blur level of the light.

The material proposed is a flat plate of resin opal finishing with the following characteristics:

- 3mm thickness.
- 80% light transmission. (assumed as no data was found on the spec sheet).

LED array.

As mentioned previously, DALIA should be bright enough in order to be visible during daytime and contrast with the background surfaces (walls and floor of the space). On this extent, DALIA should provide 3,640cd/m2. Therefore, the LED array should provide enough lumen output to reach the required luminance.

Fig. 2.29. | DALIA body layers, mirror foil.

Fig. 2.30. | DALIA body layers, light diffuser, opal finishing.

Fig. 2.31. | DALIA light sources.

In order to calculate the lumen output that the LED array should provide, reverse engineering was applied considering the transmission factors of the different layers of DALIA.

As the distance from the light sources to the last transparent cover is of 86mm the longest (varies due to the curved shape), it will be assumed that 1 lumen is equal to 1cd/m² for the calculation.

Based on the transmission factor of the different materials (92%, 88% and 80%), it is calculated that the lumen output of the light sources will be reduced in 35,2% plus the loss due to the distance from the LED chip to the transparent cover it will be assumed that the total loss is 40%. Hence, every lumen will only produce 0,6cd/m².

Therefore, the output required from the light sources is 6,067lm. (result of dividing 3640lm / 0,6).

The LED array proposed (fig. 2.32.) consist of 22.87 lineal meters of LED; LED pitch of 12,5mm. Therefore, the lumen output of the LED per meter should be at least of 266lm/m.

Therefore, the light sources proposed for DALIA (both lighting layers) have the following characteristics:

- LED strip mounted on rigid PCB
- 12,5mm LED pitch
- Colour system: RGB
- 16 BIT chip-set individually addressable
- Control protocols: Art-Net, video, DPB or SPI
- No optics, 115° light distribution
- 266lm/m – L80 B10
- Colours rendered: 281 trillions
- White point, natural
- Grayscale, 65536 levels
- Frame rate, 60fps
- Cooling, convection
- Nominal input, 24V / 48V
- Consumption, 0,35A

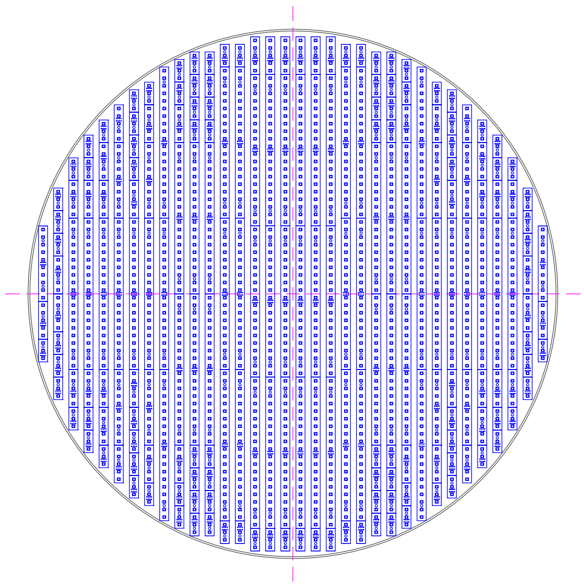


Fig. 2.32. | Array of LED light sources at the interior of DALIA. 22,87meters of lineal LED strips.

*Spec sheet of the light sources can be found on the annexes of this document (light sources).

Interior aluminium plate.

Interior aluminium plate of 4mm thickness to mount light sources. Besides being a surface to mount the light sources, works as a dissipater of the heat produced by the light sources.

Control system

Control system is the brain of DALIA, beyond full control of properties of the light sources; it allows DALIA to respond to the users, interact with them and add value to the engagement. The system can read the environment and people in order to trigger specific display of patterns, colours and movement along the light sources. In other words, it is contextual.

The system controls every single light source (LED chip) independently, by changing its properties, colour and brightness sixty times per second (frame rate). The commands for these changes are digital videos created by a real-time content generator based on data inputs. Therefore, from now own the commands will be referred to as "digital content".

Figure 2.33. illustrates the control system scheme. Afterwards, each element of the system will be described for deep understanding.

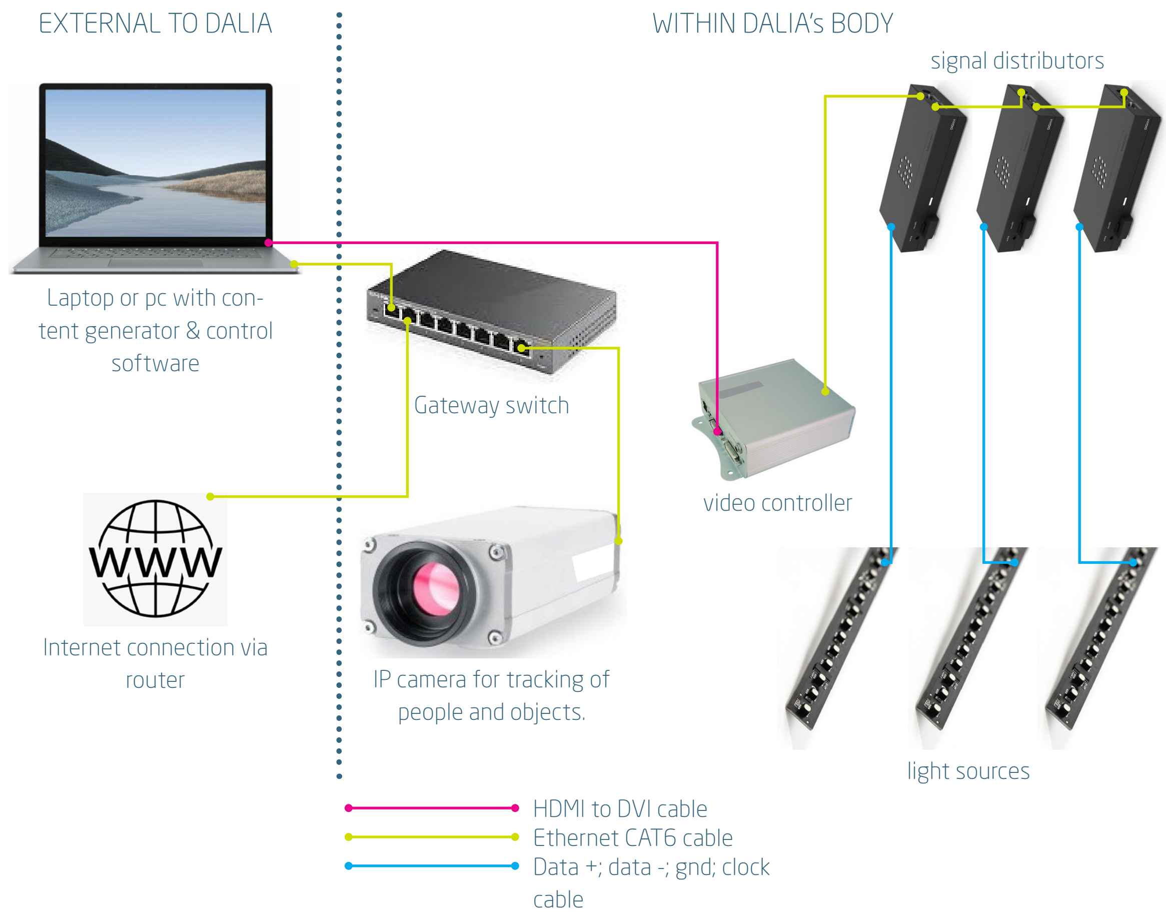


Fig. 2.33. | DALIA's control system schematic.

Content generator & control software.

The content generator and control software is one of the most critical elements of the system proposed. Based on data inputs and scheduling, it is the engine which creates the content displayed by DALIA.

Besides, is the interface to control DALIA. Therefore, the user of this interface will be the caregivers, so it should be user friendly and to do not require technical abilities to use it (most of the controls systems are complicated to use even for professional lighting designers).

The control system software should allow:

- Create generative content on video format to resolutions up to full HD (1920 x 1080). Content created will be mapped and cast to the LED array.
- Set responsive parameters as inputs for the generation of content. It will allow DALIA to be aware of the weather. For example, if it starts raining, it can mimic drops of water on the DALIA's main face (kids awareness of environment).
- Artificial intelligence algorithms for tracking on real-time video inputs (camera). For example, counting how many children are interacting with the device to trigger specific contents, if one kid the movement is slow, if two, it goes faster or changes colour (enhance and celebrate social interaction approaches).
- Images as input. Such as photographs of the kids displayed by DALIA, then they can draw on them at the writable surface (interaction, approach, and stimulate self-awareness).
- External devices input, like sensors or buttons. Although they are not considered on the original design of DALIA, allowing future easy-connection of this could improve and extend its usage.
- Content layering. To provide the opportunity of displaying different contents on the same LED array, or interconnect a DALIA sibling.
- Content presets and scheduling. To set parameters or schedules for general days and specific dates, like someones birthday. By casting contents linked to daily routines like playtime could lead to promote routines and independence.
- Mapping. On real-time, for adjusting parameters when other device is interconnected or subdividing the main face.
- Remote management. Allows caregivers to control DALIA from mobile devices or other interfaces. To promote personalisation and independent progression for each individual.
- Control protocols. DVI, Artnet.

Among the different control software existing, POET, by Skandal Tech, has been chosen as it provides the features mentioned and is in constant improvement.

IP camera.

By including a camera on DALIA, as its eyes, will be possible to track people and trigger on real-time contents.

Internet connection.

Will provide data to the control software like weather, location, specific queries to internet portals such as the web site of the educational centre, then DALIA could respond to events published on the website.

Gateway switch.

To interconnect the IP devices and generate a local network for the operation of the device.

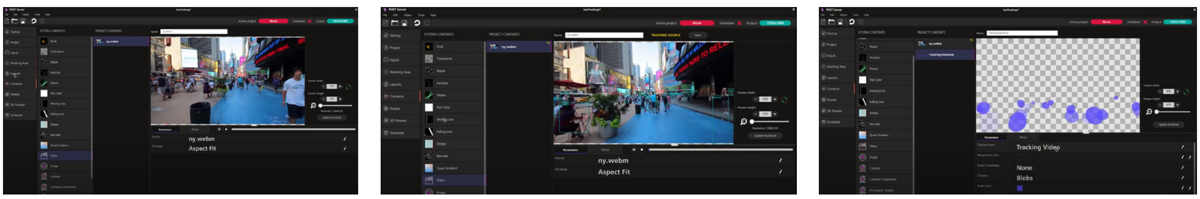
Video controller.

Will translate the information (video) coming from the control system software to lighting protocols such as Art-net. The patching of the light sources happens here; means indicate to each fixture wich pixel of the video image corresponds and translate the data of the pixel to the language of the fixture.

Signal distributors.

The information sent by video controller as lighting protocols is received by these devices and deployed to the light sources. Each device will translate the information to the specific IC protocol of the light sources, allowing faster frame rates and capacity of channels.

*Specification sheets of the camera, video controller and signal distributors can be reviewed on the annexes section of this document.



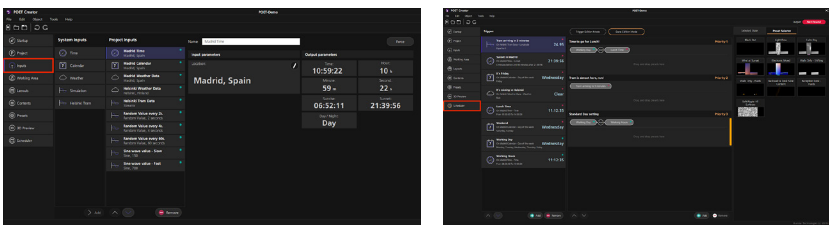


Fig. 2.34. | Control software proposed for DALIA.
(a) Real time video is captured by a camera and deployed into the software.
(b) AI module of the software detects and counts people on the scene.
(c) Software creates blobs of color based following the movement of the people on the scene.
(d) Location and weather parameters are set for the content. Allows several locations.
(e) Scheduling of contents to cast and triggers.

Co-Design

Acknowledging design as a process in which evaluation and adjustment is necessary to achieve a successful result; interviewed caregivers on chapter one were invited to participate in a demonstration of the design developed for DALIA.

Demonstration aspired to collect caregivers impressions and reactions regarding the physical design of the device and the functionality of the lighting produced as a tool for support interventions. Therefore, observations collected should be implemented on a future design revision and, before testing DALIA with individuals on the Spectrum.

For demonstration, a desktop application of a navigable virtual-reality tridimensional model of DALIA within the space analysed (the classroom) was created. Beyond the physical representation of DALIA on the space; the application displays the incident daylight which enters the space through the existing window, the artificial lighting of the classroom and, the digital content displayed by DALIA.

Natural and artificial lighting on the classroom is static on the application; therefore, it is not possible to modify the time of the day and switch off or dim the existing luminaries on the space. Nevertheless, the digital content displayed by DALIA on the application is a real-time stream of content generated through POET.

Digital content scenarios

To demonstrate some of the capabilities of DALIA to the caregivers interviewed, five digital content scenarios have been created in the content generator software considering:

- Behavioural hypothesis proposed on the Background of the Understanding Autism chapter.
- Lighting schemes suggested on the Sensory Perception section of Understanding Autism chapter.
- Prime considerations expressed by the caregivers during the interviews.
- Design drivers and lighting principles established on the Design Development section.

Scenario 1: Routine Schedule.

Its objective is to reinforce routines and independency among the children within the classroom. Schedule of this content scenario responds to the daily agenda on the classroom and, through visual clues, advises upcoming events (fig. 2.35.). The structure of the content is as follows:

- A lighting ring moves around the perimeter of DALIA accordingly to the hour of the day, like a clock face. Colour of the light changes along the day.
- On the centre of DALIA face, 5 minutes before an event, a pattern is displayed advising something is to happen. For example, playtime in the patio.

Scenario 2: Arrival of children to the classroom.

The scenario proposes the arrival of toddlers to the classroom for the first time in the morning. Its goal is to promote verbal and non-verbal communication among the children where, as a part of the daily routine they salute DALIA with a gesture and voice (when they are able to have verbal communication) and, DALIA responses by using their image (fig. 2.36.). The content is created as follows:

- DALIA's face displays sunrise colours as a back layer and, the "clock" of the first scenario as a layer above.
- When the user stands in front of DALIA, the camera captures real-time video and, the artificial intelligence of the control software detects the kid movements. The algorithms produce a particle system which follows the movement (changes on pixels detected), imitating the children gestures.

Scenario 3: Context awareness.

Meteorological events modify the behaviour of DALIA. This scenario provides context awareness to the children. As an example, it has been assumed that a specific moment, it starts to rain. DALIA, connected to internet detects that change on the weather and interrupts any other content playing, to show droplets of light simulating water and a blue effect fills DALIA with water (fig. 2.37.). To achieve this content, its presets are:

- A particles system generates the droplets of water "falling" from the top of DALIA.
- A blurred line moves upwards simulating the water fill.
- The content is triggered by a change of the weather to rain.

Scenario 4: Joint attention.

Cognitive processes are affected in children on the Spectrum, therefore understand mathematics or abstracts concepts like basic algebra is a hard task. This content exemplifies the fundamental notion of more and less. One DALIA displays two

Fig. 2.35. | DALIA displaying scenario 1 digital content; routine schedule.

Fig. 2.36. | DALIA displaying scenario 2; arrival to the classroom.

Fig. 2.37. | DALIA displaying scenario 3; context awareness.

Fig. 2.38. | DALIA displaying scenario 4; joint attention.

moving blobs of light and the second one displays four. DALIA acts as a pivot to attract the attention of toddlers (joint attention); this allows the caregiver to explain and explore the concept with the infant (fig. 2.38.).

Scenario 5: Turn it on, please.

As the caregivers can manage DALIA displayed content, it is assumed that the caregiver turns off the system, and the children, being engaged to the device, they will ask for it to have fun. So the caregiver will only turn it on again when the kid expresses its desire; it can be through verbal or non-verbal communication; like staring to DALIA and the to the caregiver in a repetitive manner.

To visualise a short clip of the content scenarios, please scan the QR codes below with the personal device of your preference or click on the link below them.

Content scenario 1; routine schedule.
CLICK HERE

Content scenario 2; arrival to classroom.
CLICK HERE

Content scenario 3; context awareness.
CLICK HERE

Content scenario 4; joint attention.
CLICK HERE

Methodology

Demonstrations were performed individually; through on-line video call, using Microsoft Teams application and, sharing the screen for the caregivers to visualise the virtual-reality application. Average duration of each demonstration was 30 minutes. As on the first round of interviews, audio was recorded.

As demonstrations were held on-line; a perception bias may have been present as the video stream within the internet was interrupted or not fluent as it will be on one to one meeting (due to COVID19 pandemic and social distancing regulations it was not possible to perform the demonstrations physically).

The structure of each presentation was as follows:

- Presentation of the behavioural hypothesis, lighting schemes and design drivers of the project.

- Explanation of the design developed; physical design intent of DALIA and functionalities.
- Display and explanation of the digital content scenarios.
- Discussion about the physical qualities of DALIA, lighting layers and the usage of the digital content.
- Closure.

Discussion

DALIA's body hardware.

Physical appearance of DALIA among the users establishes the first visual contact and can contribute to enhance participation or limit it.

Caregivers have shown an affinity to the design proposed and the physical appearance of DALIA. They have agreed that it is visually attractive and friendly; therefore, under their perspective, it can be understood that toddlers on the Spectrum will approach to the device, touch it and interact with it. Nevertheless, the perception of DALIA among the users will also depend on the individual profiles; hence, the affinity showed by the caregivers can not be assumed as an overall rule.

Concerns regarding DALIAS's "stability" arise among all the caregivers; as on the design proposed, the device stands on a "three-leg" structure. Professionals argue that children can get so excited that they can "push" or "pull" DALIA and throw it on to the ground or hit it with their hands. Therefore, structure for maintain the device standing and tolerate these actions should be revised previous to manufacture and deployment on a test, mainly to avoid the risk of physical harm to the users.

Inclusion of writable surface at DALIA's face and mirror layer on the interior has impacted positively by the interviewees; they argue that these layers will increase the proximity and tactile interaction due to the writable surface and, self-awareness provided by the translucent interior mirror.

Some of the caregivers suggest that it could be interesting if DALIA's face could work as a tactile screen. Meaning that detects the contact of the user and follows, for example, a finger; therefore, drawings can be done directly with light just like on a tablet or mobile phone. Although at the current design this technology has not been included, it should be analysed for future as indeed it could extend the interaction possibilities of DALIA.

Lighting layers.

Light produced by DALIA affects not only the individual who is making use of it, but also its surroundings by projecting Dynamic Artificial Lighting by its back.

Expectation of some of the caregivers, based on the first interview, is that the project goal was to modify the classrooms current lighting (base build). Hence, DALIA and its lighting effects was a “surprise” to some extent, as it is an independent object which produces light and for interaction. Although the expectation was not satisfied, caregivers who arise in this situation, demonstrated satisfaction on understanding DALIA and how the lighting can be used beyond its primary function. On this extent, caregivers suggest to “connect” DALIA’s system to the classroom lighting in order to extend the lighting effects into a full environment.

As per the lighting layers proposed on the design, the primary concern of the caregivers was the possibility to regulate brightness, colour and “speed” of the movements. It was explained to them that this is possible through control system and software, and was demonstrated during the session. Besides regulating the light characteristics, DALIA allows to manage each layer independently, increasing the possibilities of combinations and how it affects the users and its context.

Digital content scenarios.

Digital content scenarios created for the demonstration were presented to the caregivers as storytelling: “one day with DALIA”; through verbal explanation of the moment of the day the contents were stream in the following order: arrival to classroom, routine schedule, off, joint attention and context awareness.

The overall reaction of the participants was positive; caregivers manifested understanding and legibility of the information provided by DALIA and, they argue that the example contents created are also legible and understandable for children on the Spectrum.

Some of the participants argue that by extending the visual information to a three-dimensional space (possible through light) will lead to a better understanding of concepts by children on ASD as currently most of the visual communication is developed on two dimensions (pictograms).

The caregivers agree that the flexibility of the control software and the infrastructure of DALIA will allow to develop individual goals and contents for the toddlers supporting on that extent inclusion and individuality. Although, this will require some planning and invest time on preparing this contents, the professionals showed the will to do it.

Concerns about the usage of the control software arise during the demonstrations, as the caregivers are worried that if this will be a difficult task (to handle a new software). Therefore, control software should be revised and tested to facilitate usage of the caregivers and to do not become a bias. All of them agreed that there is a learning curve which requires time, but it will be worth it.

Demonstrations closure

After demonstrations, the participants expressed and agreed that DALIA would potentially engage children on the Spectrum and promote communication and social interaction among peers.

Caregivers showed acceptance and joy while demonstrations were carried out; by questioning specifics about the system, methods for interaction and showed excitement about having a tool like DALIA on their scholar environments.

A common observation from the participants was that DALIA seems to gather enough methodological and criteria aspects for its functioning among children on ASD, which will allow the device to have success with the users and promote the development of life-long abilities.

Caregivers coincide that DALIA could be a strong visual stimulus for toddlers on the Spectrum and, that in some cases it can become an obsession, therefore following considerations must be taken into account for an improvement of the developed design:

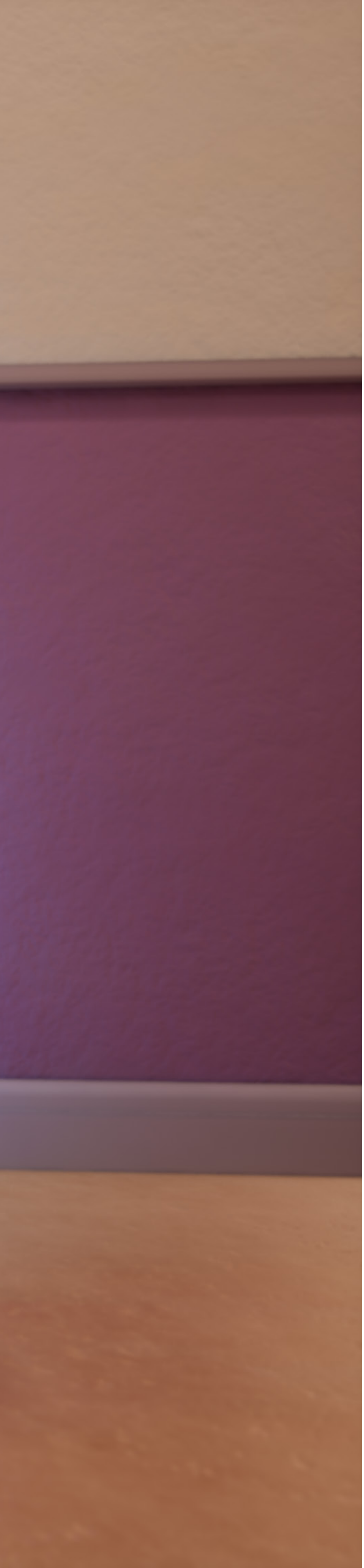
- Physical structure and "stability" of DALIA to avoid accidents and children harm (falling).
- Include a tactile surface on the face of the device that could control the lighting (drawing, writing).
- Include a sound sensor in order to allow DALIA to respond to sound and emit sounds.
- To have an artificial intelligence module capable of detecting parts of the body in order to increase interaction and response to specific gestures.
- The control system and software interface should allow to create new contents easily, in order to provide modification along time and avoid normalisation and that the users get bored (by having the same content every time).

"I would definitely have DALIA at my classroom, as it gathers methodologies and characteristics which make it a quite useful and strong stimuli for children on the Spectrum".
(Ruiz 2020, pers. com.)

"DALIA is engaging for me, I am sure it will be engaging for the toddlers; it allows to present information based on the visual system and in three dimensions".
(Piédrola 2020, pers. com.)

TESTING DALIA

Fig. 3.1. | DALIA displaying content and affecting its surroundings.



The original work plan for this project included manufacturing and testing of DALIA among individuals on the Spectrum in a scholar environment in Madrid, Spain; however, due to COVID19 pandemic was not possible to carry out these tasks on the time frame established for the development of this thesis. Nevertheless, this chapter suggests a framework and protocol for future testing when circumstances and resources are available.

While developing the literature review, interviews with caregivers and DALIA design, questions have arisen that could be subject to carry out as lighting tests among individuals in the Spectrum, such as:

- How LED lighting affects the sensory perception of children on the Spectrum?
- Will Dynamic Artificial Lighting engage individuals on ASD?
- Dynamic Artificial Lighting will promote communication and social interaction among children on the Spectrum?
- What would be the right brightness for the users?
- Will toddlers on the Spectrum will be able to associate the content displayed by DALIA on their daily routines?
- Will toddlers on the Spectrum will be able to associate changes on their environment (like raining) to the content displayed by DALIA?
- Will DALIA be engaging enough to promote joint attention of the toddlers and their caregivers?
- Does the layers of light produced by DALIA will create confusion among children?
- Which is the right contrast ratios between focal point and background for children to attend?
- Will DALIA could be such a strong stimulus that interferes with other activities?

Besides these questions, the problem statement of this project aims to validate if artificial lighting can be used as a tool for the development of communication and social interaction abilities among toddlers on the Spectrum, hence, joint attention.

On this extent, this test should measure, qualify and quantify behaviours and responses linked to joint attention and engagement produced by the usage of DALIA in order to answer the problem statement established for this thesis.

Methods

Participants

As mentioned previously, DALIA usage focuses on toddlers on the Spectrum from three to 10 years old as it is suggested to be the best age to develop abilities in communication and social interaction (Barthélémy et al. 2019). Therefore, the participants must be on the addressed range of age.

Although it is known that the Autism prevalence of male individuals is over the female (Barthélémy et al. 2019), there is no gender preference for this test.

The test should be carried out in groups of a maximum of 5 participants each (as is the number of students that are on a specialised ASD classroom in Spain) (de Miguel García 2020), and the test should be applied on at least two groups of participants.

Profile of the participants.

- Participants sensory and behavioural profiles should be acknowledged before they participate in the test in order to establish a qualitative comparison among them. Researchers suggest to use the following methods to know the participants profile:
- Participants should have been diagnosed on the Spectrum before five years of age by a physician or psychologist specialised in Autism (Orinstein et al. 2015). The diagnosis should have been developed using recognised diagnosis manuals such as the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) or the International Classification of Diseases (ICD-11).
- It is accepted to evaluate the severity of the disorder by using the ADOS-2 (Lord et al. 2018) which measures social, communication, and repetitive behaviours.
- IQ measurements to establish a scale range and create inclusion criteria (Orinstein et al. 2015).
- Sensory profile of the participants, especially about the visual system and perception. It can be defined using Winnie Dunn, which measures sensory processing (van Der Linde, Franzsen, and Barnard-Ashton 2013) or Bogdashina's sensory profile tool (Bogdashina 2007).

A comparative table of the participant's profiles is required in order to evaluate the measurements of the results.

The space

Studies argue as part of best practices for support interventions to be on familiar spaces for the participants, structured environments and, on a regular basis (daily if possible) in order to be effective (Howlin 2005; Barthélémy et al. 2019; Salvadó Salvadó et al. 2012). Hence, this proposal suggests to carry out the test into a scholar environment (classroom), which is a place where the participants might feel comfortable and is well known by them.

The test should be carried out in different classrooms (1 per group) and, during regular classes schedule in order to be understood by the participants as an element of their routines. This framework will allow to elapse the duration of the test as no extra effort is required for the families of the participants (commuting to a specific space or location).

Space will not require any specific modification in order to perform the test, as DALIA is portable and reduced on size, it allows to be installed on the classrooms by plugin it into a power source and connecting the control software through a laptop. Nevertheless, it is suggested to analyse each space where the test will take place in order to find together with the caregivers the position were DALIA should be placed.

Duration of the test

To provide a progressive approach of participants to DALIA, the proposed duration of the test is a total of four weeks in which:

- First week is for familiarisation of the participants with DALIA, measurements based on observation are required. Notes and possible adjustments to lighting effects should be considered for the following weeks.
- The caregiver should register the following three weeks, measurement, quantification and qualification of the participants' behaviours as responses to the stimulus provided by DALIA in order to analyse at the end of the test the data gathered.

Exposure to the visual stimulus produced by DALIA will be daily and controlled by the caregiver and the programmed responses through the control software.

Registration of the responses will allow comparison of the evolution of behaviours along the duration of the test in a quantitative and qualitative form.

Behavioural hypothesis

Behavioural hypothesis formulated at the Understanding Autism chapter are the behaviours to measure during the test as all of them are related to joint attention, communication, and social interaction conducts. Behavioural hypothesis formulated are:

- Hypothesis 1 (H1). Adjusting lighting properties and display patterns based on people and movement detection will create engagement and encourage social interaction among ASD children.
- Hypothesis 2. (H2). Lighting schemes will encourage communication (not necessarily verbal) among ASD children and their peers or caregivers.

- Hypothesis 3 (H3). Environment responsive lighting will propitiate a better understanding of the relationship with the user with the environment and encourage imaginative play.
- Hypothesis 4 (H4). Lighting will provide information about specific routines promoting independence and awareness among ASD children.
- Hypothesis 5 (H5). Personalisation of lighting schemes according to the user needs will reduce the risk of adverse results among the ASD population.

Based on these behavioural hypotheses, expected behaviours or responses are formulated into objective and consistent actions from the participants that will be measured in frequency, repetition and time of attention. The relationship between the expected behaviours and the hypothesis can be reviewed in figure 3.2.

RELATIONSHIP BETWEEN BEHAVIOURAL HYPOTHESES PROPOSED AND EXPECTED BEHAVIOURS

Expected Behaviours	H1	H2	H3	H4	H5
Participant approaches to DALIA when it is displaying contents.	●				
Participant approaches to DALIA when it is not displaying contents.	●				
Participant shows attention to DALIA when changes are displayed.	●		●		
Participant identifies changes on DALIA.			●	●	
Participant associates changes displayed by DALIA to changes in the context. (time, colour changing associated to routines, weather)			●	●	
Participant alters the immediate context of DALIA in order to obtain a response from DALIA.	●		●		
Participant associates changes produced by DALIA to movements of its body.	●		●		
Participant moves its body in order to obtain a response from DALIA.	●		●		
Participant associates changes in DALIA to movements of the caregiver.	●		●		
Participant requests movements of the caregiver in order to obtain a response from DALIA.	●	●	●		
Participant associates changes on DALIA to movements of a peer.	●		●		
Participant produces changes in the body of a peer in order to obtain a response from DALIA.	●	●	●		
Participant imitates movements of the caregiver in order to obtain a response from DALIA.	●		●		
Participant imitates movements of its peers in order to obtain a response from DALIA.	●		●		
Participant moves its body when DALIA is displaying a content.	●		●		
Participant moves its body when DALIA is not displaying a content.	●		●		
If DALIA is not displaying content, participant touches the device to activate a content.	●				
If DALIA is not displaying content, participant requests to the caregiver to make it display contents (verbal or non-verbal communication).	●	●			
When turning off DALIA, the participant request to the caregiver to turn it on again (verbal or non-verbal communication).	●	●			
During interaction situations with DALIA, the participant shows joint attention (with caregiver or peers).		●	●		
Participant anticipates routines by observing DALIA.		●		●	
Participant shows acceptance while working with DALIA.	●				●
Participant shows rejection while working with DALIA. (shows agitation or unable to focus on a task, angry or doest not shows interest).	●				●
Participant asks to the caregiver to work with DALIA.	●	●			
Participant uses DALIA properly (not hitting, drop it or shows rejection).	●				●
DALIA interferes on the development of other activities on the space.	●				●
Participant shows hyper or hypo-sensitivity to colours or patterns displayed by DALIA.					●
Participant shows hyper or hypo-sensitivity to brightness produced by DALIA.					●

Fig. 3.2. | Table showing the relationship between Behavioural Hypotheses and expected behaviours as a response of users to DALIA.

Procedures

Procedure

Participants will be exposed to the visual stimulus produced by DALIA daily for four weeks. At least two groups of participants must participate in order to compare results (10 participants total).

Video register will be required for the full experiment in order to review at the end the registers developed by the caregivers and the recordings.

First week.

- Contents for this period will be programmed with the participation of the caregiver responsible for the group. Contents will be displayed automatically by DALIA should include:
- Contents related to daily routines (like the clock face proposed previously).
- Contents related to weather changes. (sunny, clouds, overcast, storm)
- Contents were only the daily routine is displayed (moving ring).
- Contents were DALIA displays no light.
- Contents were interaction through body movement is active.

The contents should be programmed to occur daily; "off" and "interaction" contents should be randomised on time (do not repeat the same time two days).

Colours and patterns for the contents must be selected together with the caregiver as well as brightness intensities. During this week, these properties should not be altered on-site in order to establish a tendency line for measuring behaviours of the following weeks.

Caregiver should register daily the behaviours showed by the participants in an observation register (fig. 3.3.).

Weeks two to four.

Based on the observations registered on week one (and following), contents will be adjusted by the caregiver.

A weekly plan is necessary (develop together with caregiver) in order to create specific contents for the activities planned with DALIA. Contents should be scheduled accordingly.

In order to include DALIA into the daily routine of the children, a pictogram or visual – physical object should be developed for the toddlers to use and know when they will have activities with DALIA.

As on the first week, a daily register of behaviours is required and, additionally, a qualitative evaluation of the behaviours and their relationship with specific contents; evaluation always should be carried out based on the individual and avoid comparison among peers (fig. 3.4.).

DALIA

A Dynamic Lighting tool for development of social skills in children on the Autism Spectrum

AALBORG UNIVERSITY COPENHAGEN

Study Board of Media Technology
Msc. Lighting Design
LiD 10 | Master Thesis
Spring 2020

BEHAVIOURS OBSERVATION REGISTER

Participant Code: *Assign each participant a code for the test.

Group: *Indicate to which group does the participant belongs.

Date: *Date

EXPECTED BEHAVIOURS	EVALUATION SCALE	
	Frequency / Times the behaviour has been present	Duration of Behaviour
Participant approaches to DALIA when it is displaying contents.		
Participant approaches to DALIA when it is NOT displaying contents.		
Participant shows interest in DALIA when changes are displayed (clarify to which changes responses in the qualitative analysis section).		
Participant associates changes displayed by DALIA to changes in the context (time, colour changing, routines, weather; clarify to which changes in the qualitative analysis section).		
Participant alters the immediate context of DALIA in order to obtain a response from DALIA.		
Participant associates changes produced by DALIA to movements of its body.		
Participant produces changes on its body (movement) in order to obtain a response from DALIA.		
Participant associates changes in DALIA to movements of the caregiver.		
Participant requests movements of the caregiver in order to obtain a response from DALIA.		
Participant associates changes on DALIA to movements of a peer.		
Participant produces changes in the body of a peer in order to obtain a response from DALIA.		
Participant imitates movements of the caregiver in order to obtain a response from DALIA.		
Participant imitates movements of its peers in order to obtain a response from DALIA.		
Participant moves its body when DALIA is displaying a content.		
Participant moves its body when DALIA is NOT displaying a content.		
If DALIA is not displaying content, participant touches the device to activate a content.		
When turning off DALIA, the participant request to the caregiver to turn it on again (verbal or non-verbal communication).		
If DALIA is not displaying content, participant requests to the caregiver to make it display contents (verbal or non-verbal communication).		
During interaction situations with DALIA, the participant shows joint attention (with care-giver or peers).		
Participant anticipates routines by observing DALIA.		
Participant shows acceptance while working with DALIA.		
Participant shows rejection while working with DALIA. (shows agitation or unable to focus on a task, angry or doest not shows interest).		
Participant asks to the caregiver to work with DALIA.		
Participant uses DALIA properly (not hitting, drop it or shows rejection).		
If usage is not proper, please clarify in the qualitative analysis section the behaviour.		
DALIA interferes on the development of other activities on the space.		
Participant shows hyper or hypo-sensitivity to colours or patterns displayed by DALIA.		
Participant shows hyper or hypo-sensitivity to brightness produced by DALIA.		

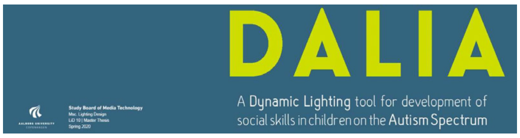
OBSERVED BEHAVIOUR - QUALITATIVE ANALYSIS

DIFFICULTIES PRESENTED DURING TEST

Related to the participant. (over-excitement, restricted interest difficulting rest of routines, symptoms of hyper or hypo-sensitivity to light)

Related to DALIA. (difficulties in finding the right place for usage, not operating correctly, fragility, difficulties operating the control software).

Fig. 3.3. | Behaviours observation register to be used by the caregivers to measure quantity and quality of the responses of the children.



COMPLEMENTARY EVALUATION REGISTER FOR SECOND TO FOURTH WEEK OF TEST

Participant Code: *Assign each participant a code for the test.

Group: *Indicate to which group does the participant belongs.

Date: *Date

Schedule different activities during the week in which DALIA is involved and create digital contents to work together with the participants for specific days and times as per the schedule.

Associate an image, pictogram, body gesture with the participants in order to incorporate DALIA into the routine.

ACTIVITY PLANNED

Please describe the specific activity and indicate if it will be carried out individually or in a group.

Timing. Please indicate the number of sessions in which this activity will be carried out, time of the day and duration.

Evaluation of the activity. Please indicate the behaviours and observations during the activity and if the objectives proposes were fulfilled.

OBJECTIVES OF THE ACTIVITY RELATED TO COMMUNICATION AND SOCIAL INTERACTION

DIGITAL CONTENTS DEVELOPED

Please describe or indicate the contents developed for the activity.

Fig. 3.4. | Proposal for activities with DALIA and evaluation of qualitative behaviours and results

Results

Once the test is over, collected data and video recordings should be analysed carefully. The primary objective of this analysis should help the research to determine if DALIA is engaging among children on the Spectrum by answering the following questions:

- What is the variability of interest about DALIA among the participants?.
- Does the interest was persistent along time?.
- How much time does the participants spent interacting with DALIA? (per interaction).
- Does the participants showed spontaneous communication with peers or caregivers about DALIA?.
- What is the most symbolic interaction observed among participants?.
- Does the participants showed restricted interest about DALIA?. If it is the case, does this interest restricted them to carry out other activities?.
- Does participants showed interest for sharing with peers the experiences with DALIA?

This test proposes that by answering addressed questions, it will be possible to establish if Dynamic Artificial Lighting can be used as a tool for developing communication and interaction abilities on toddlers on the Spectrum.

CONCLUSIONS

The prevalence rate of Autism is continuously growing. Researchers attribute increments to the improvement of diagnostic methods and early detection programs, which have now incorporated sensory disorders as a diagnostic criteria, driving researchers to explore the usage of sensory stimuli during support interventions of people on the Spectrum.

Literature review, analysis of empirical evidence and interviews with professionals on Autism has revealed a breach for using artificial light as a tool during support interventions for the development of joint attention, communication and social interaction skills among children on the Spectrum.

Being the visual system the most preserved among the population on ASD and, light the most apparent visual stimuli, this thesis explored how artificial light can be used as stimuli in educational environments in order to promote communication and social interaction among toddlers on Autism.

As Autism is characterised by being a disharmonic spectrum, there is no "one size fits all" solution for support interventions. Nevertheless, the possibility to adapt stimuli and perception of space as required by each individual seems to be possible through the usage of artificial lighting. Therefore, this thesis proposed the design of DALIA; a Dynamic Artificial Lighting tool which considers a wide range of characteristics of people on the Spectrum in order to offer them engagement, flexibility, interactivity and responses to contextual events that could lead to the development of joint attention, communication and social interaction abilities on children on the Spectrum.

In order to provide such flexibility, adaptation, interaction and engagement, this project pushes the boundaries of lighting beyond its primary function (to provide visibility). It proposes Dynamic Artificial Lighting as a system which integrates Autism methodologies and, physical and digital contexts. While DALIA gets affected by its context and users, it also affects its surroundings.

Although it was no possible to test DALIA with children on the Spectrum; a digital demonstration of its capabilities was performed for professional ASD caregivers. It revealed that the usage of Dynamic Artificial Lighting In Autism has a potential to promote joint attention, communication and social interaction among the population on the Spectrum. Therefore, this thesis proposes a protocol for testing DALIA on future work.

Dynamic Artificial Lighting arises as a possible answer to explore new forms of communication and education of people on the Spectrum, nevertheless is acknowledged that it is not the only one. Projects such as Pictogram Room or Magic Room have explored and put on evidence how interaction and visual stimulus can promote specific behaviours on children on the Spectrum in order to offer a possibility of a better quality of life.

Future Research

While developing this thesis, a lack of knowledge about the effects of light on people in Autism and, the relationship of sensory difficulties and lighting arise. Therefore, this project concludes proposing research questions to encourage the formulation of empirical and evidence-based knowledge on future work:

- Effects of fluorescent and incandescent lighting sources upon individuals on the Spectrum has been explored in the past (Colman et al. 1976), revealing some adverse effects of this light sources among the population on ASD. As fluorescent and incandescent light sources are becoming obsolete, the research should be updated with current available lighting technologies. Hence the research question arises: What are the effects of LED lighting upon repetitive behaviours in individuals on the Spectrum?.
- Authors and caregivers interviewed refer to visual hyper-sensitivity on individuals on Autism produced by light (Bogdashina 2007). On this extent, most of them refer to this difficulty when the individuals look straight to the light sources (luminaires or sun: direct lighting) but, what happens when the light source is shielded or indirect: Does indirect and diffuse lighting produces visual hyper-sensitivity on people on the Spectrum?
- Publications suggest cold CCT of lighting could promote relaxation and creativity among individuals on the Spectrum (Sensing 2020). Nevertheless, no evidence supports this theory. On this extent: What are the behavioural effects of different CCT upon people on the Spectrum?
- People on the Spectrum tend to fix their attention on high-pixel saliency pixels on scenes (Behrmann, Thomas, and Humphreys 2006; Becchio, Mari, and Castiello 2010). What are the contrast ratios that call the attention of people on the Spectrum?

Mentioned research questions might lead to an extensive understanding of the relationship between light, lighting and Autism, so we, as designers, could develop more inclusive and comfortable spaces for this population.

LIST OF FIGURES

Preface

Figure 0.1. | Light-Art piece at Tieto Headquarters in Espoo, Finland: Photograhpy by Onni Tappola, Lighting Design Collective archive.

Figure 0.2. | Black waves by teamLab exhibition at Espacio Fundación Telefónica in Madrid, Spain: Own production.

Figure 0.3. | Pictogram representing minorities: Own production.

Figure 0.4. | Water Light Graffiti by Antonin Fourneau, adapted: https://www.digitalavmagazine.com/2012/08/13/water-light-graffiti-una-innovadora-superficie-de-leds-iluminados-al-contacto-con-el-agua/

Figure 0.5. | Project process model: Own production.

Chapter I. Understanding Autism

Figure 1.1. | Educational play light table by Edu2, adapted: https://www.google.com/url?sa=i&url=http%3A%2F%2Fwww.edu2.lt%2Fen%2Fproduct%2Feducational-play-light-table%2F&psig=AOvVaw0sZiQh_X2SCXChXZrLHalY&ust=1587134811068000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCMCyp4eY7egCFQAAAAAdAAAAABAP

Figure 1.2. | Cascading brain and behaviour changes in the development of Autism (Piven, Elison and Zylka 2017,5), reprinted.

Figure 1.3. | Table showing the contexts, criteria and typical behaviours established by DSM-5 for ASD diagnosis (American Psychiatric Association 2013): Own production.

Figure 1.4. | Pictograms representing emotions, Arasaac.org: http://www.arasaac.org/pictogramas_color.php?p=2%7C3%7C6%7C40&busqueda=basico&id_subtema=86

Figure 1.4A. | Table showing correlations between DSM-5 diagnosis contexts and artificial lighting applications, followed by formulation of behavioural hypothesis (American Psychiatric Association 2013): Own production.

Figure 1.5. | Interactive Light-Art feature, Anonymous by Lighting Design Collective in Helsinki, Finland, adapted: https://losslessphoto.wordpress.com/tag/ovo/

Figure 1.6. | BruumRuum! Reactive Light-Art installation in the public domain by Artec 3 and David Torrents, adapted: http://cargocollective.com/artec3_old/BruumRuum

Figure 1.7. | OSC commands through personal device, adapted: https://www.pro-tools-expert.com/logic-pro-expert/logic-pro-blog/2016/02/05/free-logic-pro-x-key-commands-template-for-touchosc

Figure 1.8. | NOVA three-dimensional display system by Martina Eberle and Christoph Niederberger, adapted: https://arthurtseng.wordpress.com/2010/01/14/voxel-facades-technology/

Figure 1.9. | The Way of the Sea Light-Art by teamLab at Borderless Museum, adapted: https://www.pinterest.com/pin/295267319321511554/

Figure 1.9A. | Table showing correlations between Bogdashina's sensory experiences, visual processing complications and proposed lighting applications (Bogdashina 2007): Own production.

Figure 1.10. | A three-stage model of human visual information processing, adapted: (Ware 2009, 21).

Figure 1.11. | % Flicker vs. Flicker Frequency on LED light sources. Eldoled White paper, Flicker Performance in LED lighting. https://www.eldoled.com/cms_files/Downloads/Natural%20Dimming/White%20paper_Flick-

er%20performance%20in%20LED%20lighting.pdf

Figure 1.12. | Castics caused by light refraction. Raytrace installation by Benjamin Hubert at Cosentino, adapted: https://icosentino.imgix.net/fr-ca/wp-content/uploads/2019/04/Raytrace-by-Benjamin-Hubert-of-LAYER-for-Dekton.-Image-Credit-David-Zanardi-2-1.jpg?auto=format%2Ccompress&fit=crop

Figure 1.13. | Dust particles suspended on air shimmers when hit by light, adapted: https://www.blueair.com/be/blueair-life/air-purifiers-at-home/construction-dust.html

Figure 1.14. | Spinning peg-top toy with integrated lighting, adapted: https://www.amazon.ca/Baoblaze-Novel-Spinning-Peg-Top-Outdoor/dp/B07FYBQJBK

Figure 1.15. | Bouncing ball, shimmers when bounced, adapted: https://www.pinterest.com/pin/594686325776569237/

Figure 1.16. | Lighting sticks with integrated fiber optics, adapted: https://es.aliexpress.com/item/32597273862.html

Figure 1.17. | Relationship between prime lighting considerations expressed by interviewees, behavioural hypothesis and lighting principles: Own production.

Chapter II. DALIA Design

Figure 2.1. | Computer Generated Image of a children interacting with DALIA, a dynamic-lighting based tool for the development of lifelong abilities among children on Autism. Own production.

Figure 2.2. | People lying on the floor taking a sunbath during the exhibition the Weather Project in 2003. The gigantic artificial sun called people attention to the level of invite them to take a sunbath. Reprint. https://olafureliasson.net/archive/artwork/WEK101003/the-weather-project

Figure 2.3. | People interacting with the footpads on The Pool by Jen Lewin Studio. The footpads reacts to people weight, position and direction of movement with lighting effects. Reprint. https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.cincinnati.com%2Fpicture-gallery%2Fentertainment%2F2017%2F10%2F13%2Fwhat-blink-actually-looks---and-feels---like%2F106594446%2F&psig=AOvVaw1CYG8BnNs6s4fcWbxyqlAX&ust=1589217552964000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCJjfk9LoqekCFQAAAAAdAAAAABAD

Figure 2.4. | Silo 468 by Lighting Design Collective, lighting "movement" is triggered by context information like weather. Reprint. https://www.plataformaarquitectura.cl/cl/02-254353/20-propuestas-ganadoras-de-los-premios-lamp-lighting-solutions-2013/5176def0b3fc4b748700020c

Figure 2.5. | Kid interacting with the images displayed by the projector while using Pictogram Room video-games. Reprint. https://www.semanticscholar.org/paper/Pictogram-Room%3A-Natural-Interaction-Technologies-to-Casas-Sevilla/fa433e07ab912ba6dca4ebe2dc0fe3e95c76dc69

Figure 2.6. | Kid recognising himself and his body parts through Pictogram Room. Reprint. http://www.pictogramas.org/proom/init.do?method=gameTab

Figure 2.7. | Person imitating postures displayed by Pictogram Room games. Reprint. http://www.pictogramas.org/proom/init.do?method=gameTab#

Figure 2.8. | Arrangement of sensory devices along Magic Room (Garzotto and Geslomini 2018, 40). Reprint.

Figure 2.9. | Picture of Magika-Ludomi, the evolution of the Magic Room. Reprint. https://ludomi.polimi.it/en/ludomi-welcome/

Figure 2.10. | Conceptual Sketch of DALIA as a system. Own production.

Figure 2.11. | Symbol of a puzzle piece which used to represent the Autism. Reprint. https://intheloopabout-neurodiversity.wordpress.com/2019/03/20/the-ableist-history-of-the-puzzle-piece-symbol-for-autism/

Figure 2.12. | Rainbow-coloured infinity symbol which currently represents the population on Autism. Re-print. https://en.wikipedia.org/wiki/Autism_rights_movement

Figure 2.13. | Abstraction of infinity couloured for DALIA concept. Own production.

Figure 2.14. (a) | Scholar centre in Madrid, top view of the building, "n" shape floorplan. Adapted. https://www.google.com/maps/@40.4061606,-3.7063878,100m/data=!3m1!1e3

Figure 2.14. (b) | Scholar centre in Madrid, perspective view of the centre, blue lines indicate the location of the classroom to study. Adapted. https://www.google.com/maps/@40.4058475,-3.705799,68a,35y,296.44h,38.98t/data=!3m1!1e3

Figure 2.15. (a) | Floorplan of the classroom object of the study. Own production.

Figure. 2.15. (b) | Section view "A" of the classroom object of the study. Own production.

Figure 2.16. | Picture of the interior room were finishings on surfaces and fluorescent luminaires can be observed (de Miguel Garcia 2020).Reprinted.

Figure 2.17. | Computer generated image of the digital model created for the lighting calculations. Own production.

Figure 2.18. | CGI of the sunlight incidence on the interior of the room from 9:00 to 12:00 during summer solstice (June 21st). Own production.

Figure 2.19. (a) | Calculations surfaces with different finishings for luminance calculations, roughcast plas-tering white painted. Own production.

Figure 2.19. (b) | Calculations surfaces with different finishings for luminance calculations, roughcast plas-tering purple painted. Own production.

Figure 2.20. | Graphic showing luminance values obtained from incident daylight on calculation surfaces with roughcast plastering, white painted. Own production.

Figure 2.21. | Graphic showing luminance values obtained from incident daylight on calculation surfaces with roughcast plastering, purple painted. Own production.

Figure 2.22. (a) | Luminance ratios. Reprinted. (Michel 1996, 33)

Figure 2.22. (b) | Brightness as a function of the background. Reprinted. (Michel 1996, 14)

Figure 2.23. | Heights of children from three to ten years old and golden ratio. Own production.

Figure 2.24. | Proportion of DALIA over 3 year old children. Own production.

Figure 2.25. | Position and proportions of DALIA among three, six and 10 years old children. Own production.

Figure 2.26. | DALIA light layers. (a) Diffused light layer. (b) Reflected light layer. Own production.

Figure 2.27. | Diffused and reflected light layers of DALIA. Own production.

Figure 2.28. | Body hardware components of DALIA. Own production.

Figure 2.29. | DALIA body layers, mirror foil. Reprint. https://www.laminotech.com/producto/lamina-so-lar-metalizada-alu-70-interior/

Figure 2.30. | DALIA body layers, light diffuser, opal finishing. Reprint. https://www.3-form.com/downloads/

3form-finishes-042220.pdf

Figure 2.31. | DALIA light sources. Reprint. https://schnick.schnack.systems/en/news/and-action-the-new-c12-led-strips-set-the-perfect-stage-for-the-marrakech-international-film-festi/

Figure 2.32. | Array of LED light sources at the interior of DALIA. 22,87meters of lineal LED strips. Own production.

Figure 2.33. | DALIA's control system schematic. Own production.

Figure 2.34. | Control software proposed for DALIA. Reprinted. http://www.skandal.tech/

Figure 2.35. | DALIA displaying scenario 1 digital content; routine schedule. Own production.

Figure 2.36. | DALIA displaying scenario 2; arrival to the classroom. Own production.

Figure 2.37. | DALIA displaying scenario 3; context awareness. Own production.

Figure 2.38. | DALIA displaying scenario 4; joint attention. Own production.

Chapter III. Testing DALIA

Figure 3.1. | DALIA displaying content and affecting its surroundings. Own production.

Figure 3.2. | Table showing the relationship between Behavioural Hypotheses and expected behaviours as a response of users to DALIA. Own production.

Figure 3.3. | Behaviours observation register to be used by the caregivers to measure quantity and quality of the responses of the children. Own production.

Figure 3.4. | Proposal for activities with DALIA and evaluation of qualitative behaviours and results. Own production.

REFERENCES

American Psychiatric Association eds. 2013. *Diagnostic and Statistical Manual of Mental Disorders: Dsm-5.* 5th ed. Washington, D.C.: American Psychiatric Association.

ASDEU Programme, and Manuel Posada de la Paz. 2018. *'Autism Spectrum Disorders in the European Union (ASDEU) Executive Summary 12/09/2018'.* European Parliament, ASDEU. http://asdeu.eu/wp-content/uploads/2016/12/ASDEUExecSummary27September2018.pdf

Autism Europe. 2020. *'About Autism – Autism Europe'.* Accessed 11 January 2020. https://www.autismeurope.org/about-autism/.

Autism Europe. 2020. *'Diagnostic Criteria – Autism Europe'. Autism Europe - Diagnostic Criteria.* Accessed 23 February 2020. https://www.autismeurope.org/about-autism/diagnostic-criteria/.

Autism Europe. 2020 *'Prevalence Rate of Autism'. Autism Europe - Diagnostic Criteria.* Accessed 23 February 2020. https://www.autismeurope.org/about-autism/prevalence-rate-of-autism/.

Barth, Friedrich G. 2012. *'Sensory Perception: Adaptation to Lifestyle and Habitat'.* In Sensory Perception: Mind and Matter. Vienna: Springer-Verlag/Wien.

Barth, Friedrich G, Patrizia Giampieri-Deutsch, and Hans-Dieter Klein. 2012. *Sensory Perception: Mind and Matter.* https://doi.org/10.1007/978-3-211-99751-2.

Barthélémy, Catherine, Joaquín Fuentes, Patricia Howlin, and Rutger van der Gaag. 2019. *'People with Autism Spectrum Disorder: Identification, Understanding, Intervention. Third Edition'.* Autism Europe. https://www.autismeurope.org/wp-content/uploads/2019/09/People-with-Autism-Spectrum-Disorder.-Identification-Understanding-Intervention_compressed.pdf.pdf.

Becchio, Cristina, Morena Mari, and Umberto Castiello. 2010. *'Perception of Shadows in Children with Autism Spectrum Disorders'.* PLOS ONE 5 (5): e10582 (5). https://doi.org/10.1371/journal.pone.0010582.

Behrmann, Marlene, Cibu Thomas, and Kate Humphreys. 2006. *'Seing It Differently: Visual Processing in Autism'.* Trends in Cognitive Sciences 10 (6): 258-64. https://doi.org/10.1016/j.tics.2006.05.001.

Bogdashina, Olga. 2010. *Autism and the Edges of the Known World: Sensitivities, Language, and Constructed Reality.* London: Jessica Kingsley.

Bogdashina, Olga. 2007. *Percepción Sensorial en el Autismo y Síndrome de Asperger: Experiencias Sensoriales Diferentes, Mundos Perceptivos Diferentes.* Ávila: Autismo Ávila.

Charlton, Rebecca Ann. 2016. *'What Happens When People with Autism Grow Old?'* Online Journal. The Conversation. 10 October 2016. http://theconversation.com/what-happens-when-people-with-autism-grow-old-65572.

Colman, Richard S., Fred Frankel, Edward Ritvo, and B. J. Freeman. 1976. *'The Effects of Fluorescent and Incandescent Illumination Upon Repetitive Behaviors in Autistic Children'.* Journal of Autism and Childhood Schizophrenia 6 (2): 157–62. https://doi.org/10.1007/BF01538059.

'Control of Fire by Early Humans'. 2020. In Wikipedia. https://en.wikipedia.org/w/index.php?title=Control_of_fire_by_early_humans&oldid=953168469.

Crosman, Cassandra. 2019. *'The Ableist History of the Puzzle Piece Symbol for Autism'.* In the Loop About Neurodiversity (blog). 20 March 2019. https://intheloopaboutneurodiversity.wordpress.com/2019/03/20/the-ableist-history-of-the-puzzle-piece-symbol-for-autism/.

Coxon, Ian. 2015. 'Chapter 1. Fundamental Aspects of Human Experience: A Phenomeno (Logical) Explanation'. In *Experience Design: Concepts and Case Studies,* edited by Peter Benz, 11-22. London; New York: Bloomsbury Academic.

Darbellay, Frédéric, Zoe Moody, and Todd I. Lubart, eds. 2017. *Creativity, Design Thinking and Interdisciplinarity.* Creativity in the Twenty First Century. Singapore: Springer.

Der Linde, Janine van, Denise Franzsen, and Paula Barnard-Ashton. 2013. *'The Sensory Profile: Comparative Analysis of Children with Specific Language Impairment, Adhd and Autism'.* South African Journal of Occupational Therapy 43 (3): 34–40.

Eliasson, Olafur. 2009. *'Your Engagement Has Consequences'.* In Experiment Marathon, Serpentine Gallery, Reykjavik Art Museum. Emma Ridgway. https://s3-eu-west-1.amazonaws.com/olafureliasson.net/texts/Your_Engagement_Has_Consequences_109985.pdf.

Folstein, Susan, and Michael Rutter. 1977. *'Infantile Autism: A Genetic Study of 21 Twin Pairs -Folstein- Journal of Child Psychology and Psychiatry - Wiley Online Library'.* Journal of Child Psychology and Psychiatry 18: 297-321.

Foundation UEFA pour l'enfance, FIRAH, and Philippe Garnier. 2017. *'Autism and New Technologies: Literature Review on the Use of Digital Tools to Help Develop Non-Verbal Communication and Social Interaction Skills of Children with Autism Spectrum Disorder (ASD).'* Resource Center Applied Research and Disability. https://www.firah.org/upload/activites-et-publications/revue-de-litterature/autisme-et-nouvelles-technologies/eng-autisme-nouvelles-tech.pdf.

Gaffrey, Michael S., Natalia M. Kleinhans, Frank Haist, Natacha Akshoomoff, Ashley Campbell, Eric Courchesne, and Ralph-Axel Müller. 2007. *'Atypical Participation of Visual Cortex During Word Processing in Autism: An Fmri Study of Semantic Decision'.* Neuropsychologia 45 (8): 1672–84. https://doi.org/10.1016/j.neuropsychologia.2007.01.008.

Garzotto, Franca, and Mirko Gelsomini. 2018. *'Magic Room: A Smart Space for Children with Neurodevelopmental Disorder'.* IEEE Pervasive Computing 17 (1): 38–48.

Gil Morán, Elena. 2020. *Autism and Lighting, Interviews with Professional on ASD* Interview by Sergio David Hernández Pascual. Personal Interview, Video Call.

Grandin, Temple. 2006. *Thinking in Pictures: And Other Reports from My Life with Autism.* 2nd Vintage Books ed. New York: Vintage Books.

Hazlett, Heather Cody, Hongbin Gu, Brent C. Munsell, Sun Hyung Kim, Martin Styner, Jason J. Wolff, Jed T. Elison, et al. 2017. *'Early Brain Development in Infants at High Risk for Autism Spectrum Disorder'.* Nature 542 (7641): 348–51. https://doi.org/10.1038/nature21369.

Hegde, Asha. 2015. *'Sensory Sensitivity and the Built Environment: Rethinking Their Design Palette Can Help Architects and Lighting Professionals Create Better Classrooms and Other Environments for Those with Autism'.* LD+A Magazine 45 (1): 56–60.

Hernández, Juana. 2020. *Autism and Lighting, Interviews with Professional on ASD* Interview by Sergio David Hernández Pascual. Personal Interview, Video Call.

Herrera, Gerardo, Xavier Casas, Javier Sevilla, Luis Rosa Escribano, Carlos Pardo Carpio, Javier Plaza, Rita Jordan, and Sylvain Le Groux. 2012. *'Pictogram Room: Aplicación de tecnologías de interacción natural para el desarrollo del niño con autismo'.* Anuario de psicología clínica y de la salud = Annuary of Clinical and Health Psychology, no. 8: 41–46.

Hespanhol, Luke. 2017. *Media Architecture Compendium: Digital Placemaking.* Stuttgart: Avedition.

Holaday, Bonnie. 2012. *History of Autism.* South Carolina Nurse 19 (2): 12-13.

Howlin, P. 2005. 'The Effectiveness of Interventions for Children with Autism'. In *Neurodevelopmental Disorders, edited by W. W. Fleischhacker and D. J. Brooks,* 101–19. Vienna: Springer. https://doi.org/10.1007/3-211-31222-6_6.

Jackson, Davina, Mary-Anne Kryiakou, Vesna Petresin, Thomas Schielke, Peter Weibel, and Peter Droege, eds. 2015. *Superlux: Smart Light Art, Design and Architecture for Cities.* London: Thames & Hudson.

Kana, Rajesh K., Timothy A. Keller, Vladimir L. Cherkassky, Nancy J. Minshew, and Marcel Adam Just. 2006. 'Sentence Comprehension in Autism: Thinking in Pictures with Decreased Functional Connectivity'. Brain 129 (9): 2484–93. https://doi.org/10.1093/brain/awl164.

Kanner, Leo. 1943. *'Autistic Disturbances of Affective Contact'.* Nervous Child 2: 217–50.

Leung, Linda. 2015. 'Chapter 4. Experiential Equality and Digital Discrimination'. In *Experience Design: Concepts and Case Studies,* edited by Peter Benz, 45-53. London; New York: Bloomsbury Academic.

Lord, Catherine, Mayada Elsabbagh, Gillian Baird, and Jeremy Veenstra-Vanderweele. 2018. *'Autism Spectrum Disorder'.* The Lancet 392 (10146): 508–20. https://doi.org/10.1016/S0140-6736(18)31129-2.

Lucero, Andrés, Jon Mason, Alexander Wiethoff, Bernt Meerbeek, Henrika Pihlajaniemi, and Dzmitry Aliakseyeu. 2016. *'Rethinking Our Interactions with Light'.* Interactions 23 (6): 54–59. https://doi.org/10.1145/3003334.

Ludomi, and Politecnico de Milano. n.d. *'Magika | Un Progetto Ludomi'.* Accessed 24 May 2020. https://ludomi.polimi.it/.

Lueder, Rani, and Valerie J. Berg Rice. 2008. *Ergonomics for Children: Designing Products and Places for Toddlers to Teens.* Boca Raton, Fla. : London: CRC ; Taylor & Francis [distributor].

Mesa, Eva. 2020. *Autism and Lighting, Interviews with Professional on ASD* Interview by Sergio David Hernández Pascual. Personal Interview, Video Call.

Michel, Lou. 1996. *Light: The Shape of Space: Designing with Space and Light.* New York, NY: Wiley.

Miguel García, Beatriz. 2020. *Autism and Lighting, Interviews with Professional on ASD* Interview by Sergio David Hernández Pascual. Personal Interview, Video Call.

Orinstein, Alyssa J., Joyce Suh, Kaitlyn Porter, Kaitlin A. De Yoe, Katherine E. Tyson, Eva Troyb, Marianne L. Barton, Inge-Marie Eigsti, Michael C. Stevens, and Deborah A. Fein. 2015. *'Social Function and Communication in Optimal Outcome Children and Adolescents with an Autism History on Structured Test Measures'.* Journal of Autism and Developmental Disorders 45 (8): 2443–63. https://doi.org/10.1007/s10803-015-2409-6.

Oxford English Dictionary. 2020. *'Flexibility, n.'* In OED Online. Oxford University Press. http://www.oed.com/view/Entry/71523.

Pictogram Room. n.d. *'Pictogram Room'.* Accessed 23 May 2020. http://www.pictogramas.org/proom/init.do?method=gameTab#.

Piédrola, Carmen. 2020. *Autism and Lighting, Interviews with Professional on ASD* Interview by Sergio David Hernández Pascual. Personal Interview, Video Call.

Piven, J., J.T. Elison, and M. J. Zylka. 2017. *'Toward a Conceptual Framework for Early Brain and Behaviour Development in Autism'.* Molecular Psychiatry 22(10): 1385-94. https://doi.org/10.1038/mp.2017.131.

Pop, Susa, ed. 2012. *Urban Media Cultures.* Ludwigsburg: avedition.

Ritter, Joachim, ed. 2019. *Proceedings PLDC 8th Global Lighting Design Convention, 23. - 26. October, 2019 in Rotterdam / NL -Merging Masterminds-.* VIA-Verlag, Joachim Ritter e.K. www.via-verlag.com

Robertson, Caroline E., and Simon Baron-Cohen. 2017. *'Sensory Perception in Autism.'* Nature Reviews Neuroscience 18 (11): 671–84. https://doi.org/10.1038/nrn.2017.112.

Rosenius, Tapio, and Signify Lighting University. 2017. *'Let's Move Towards Dynamic Environments'. Webinar.* Signify Lighting University. https://www.signify.com/global/lighting-academy/browser/webinar/towards-dynamic-environments

Ruiz Casas, Beatriz. 2020. *Autism and Lighting, Interviews with Professional on ASD* Interview by Sergio David Hernández Pascual. Personal Interview, Video Call.

Salvadó Salvadó, B., M. Palau Baduell, M. Clofent Torrentó, M. Montero Camacho, and Miguel Angel Hernández Latorre. 2012. *'Modelos De Intervención Global En Personas Con Trastorno Del Espectro Autista.'* Revista De Neurología 54 (1): 63,71

Sensing, Konica Minolta. 2020. *'How Light Can Help Autistic Children'.* Konica Minolta Sensing Americas. 2020. https://sensing.konicaminolta.us/blog/how-light-can-help-autistic-children/.

Schielke, Thomas, ed. 2015. *'Transforming Luminous Pixels into Brand Experiences.'* In Superlux: Smart Light Art, Design and Architecture for Cities, 1st ed., 96–103. London: Thames & Hudson.

Schiller, Brad. 2010. *'7. Digital Lighting: The Future is Here'. In The Automated Lighting Programmer's Handbook.* Oxford, United Kingdom: Taylor & Francis Group. http://ebookcentral.proquest.com/lib/aalborguniv-ebooks/detail.action?docID=690550

Smuts, Aaron. 2009. *'What Is Interactivity?'* The Journal of Aesthetic Education 43 (4): 53–73.

Spectrum Suite. 2020. *'Meet Judy Singer Neurodiversity Pioneer'.* My Spectrum Suite (blog). 2020. http://www.myspectrumsuite.com/meet-judy-singer/.

Ware, Colin. 2009. *Information Visualization: Perception for Design. 2. ed.,* [Nachdr.]. The Morgan Kaufmann Series in Interactive Technologies. Amsterdam: Elsevier [u.a.].

Wikipedia. 2020. *'Autism Rights Movement'.* In Wikipedia. https://en.wikipedia.org/w/index.php?title=Autism_rights_movement&oldid=956358614.

Wing, Lorna. 1981. *'Asperger's Syndrome: A Clinical Account'.* Psychological Medicine 11 (1): 115–29. https://doi.org/10.1017/S0033291700053332

Wolff, Sula. 2004. *'The History of Autism'.* European Child & Adolescent Psychiatry 13 (4). https://doi.org/10.1007/s00787-004-0363-5

Zika, Fay. 2013. *'Colour and Sound: Transcending the Limits of the Senses. Chapter 2'. In Light Image Imagination.* Amsterdam, Netherlands, The Amsterdam University Press. http://ebookcentral.proquest.com/lib/aalborguniv-ebooks/detail.action?docID=3001925

ANNEXES

Annexes of this project can be accessed digitally by scanning the QR code next to the reference or by clicking on the link below each reference.

Chapter I. Understanding Autism

Transcription of interview to Beatriz de Miguel García in Original Language (spanish)
LINK HERE

Transcription of interview to Beatriz Ruiz Casas in Original Language (spanish)
LINK HERE

Transcription of interview to Carmen Piédrola in Original Language (spanish)
LINK HERE

Transcription of interview to Elena Gil Morán in Original Language (spanish)
LINK HERE

Transcription of interview to Eva Mesa in Original Language (spanish)
LINK HERE

Transcription of interview to Juana Hernández in Original Language (spanish)
LINK HERE

Chapter II. DALIA Design

Specsheet of lightsources
LINK HERE

Specsheet of mirror foil
LINK HERE

Specsheet of resins
LINK HERE

Specsheet of IP camera
LINK HERE

Specsheet of video converter
LINK HERE

Specsheet of signal distributors
LINK HERE

Chapter III. Testing DALIA

Behaviours observation register
LINK HERE

Observation register; complementary evaluation
LINK HERE

AALBORG UNIVERSITY
COPENHAGEN

STUDY BOARD OF MEDIA TECHNOLOGY

Master's Programme in Lighting Design

June, 2020

Copenhagen, Denmark

DALIA

A Dynamic Artificial Lighting tool for development of communication and social abilities in children on the Autism Spectrum

a master thesis by

SERGIO DAVID HERNÁNDEZ PASCUAL

contact

sherna16@student.aau.dk

arq.pascual@gmail.com