

Plant-Driven Design and Phytotechnology to improve the built environment

Original

Plant-Driven Design and Phytotechnology to improve the built environment / Dominici, Laura; Comino, Elena; Peruccio, Pier Paolo. - ELETTRONICO. - The Design After:(2019), pp. 169-181. (Intervento presentato al convegno The Design After. Cumulus Conference Bogota 2019 tenutosi a Bogotá, Colombia nel Oct 30 – Nov 1/2019).

Availability:

This version is available at: 11583/2838127 since: 2020-07-02T20:47:19Z

Publisher:

Cumulus International Association of Universities and Colleges of Art, Design and Media. Aalto University,

Published

DOI:

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

THE DESIGN AFTER



Cumulus Conference Proceedings Bogota 2019

Cumulus Conference
Proceedings Series
06/2019 Bogota



Cumulus Conference Proceedings
The Design After
Bogota, Colombia
Oct 30 – Nov 1/2019
<https://www.cumulusbogota2019.org/>

Chair

Hernando Barragán
Conference Manager / Dean, School of Architecture
and Design
Claudia Mejía
Head, Architecture Department
Ricardo Sarmiento
Head, Design Department

Scientific Committee

Isabel Arteaga
Andrés Burbano
Daniel H. Nadal
Cesar Peña

Editorial Assistant

Melissa Ferro

Graphic Conceptualization

Cumulus Bogota 2019
Andrea Amin
Constanza Diaz del Castillo

Layout Designer

Adriana Páramo
Layout design in reflection of the cumulus
conference proceedings series graphical concept
by Jani Pulkka 2018

© Universidad de los Andes
School of Architecture and Design
Bogota, Colombia
<https://arqdis.uniandes.edu.co/>

© Cumulus International Association of
Universities and Colleges of Art, Design and
Media. Aalto University, School of Arts, Design
and Architecture
PO BOX 31000, FI-00076 Aalto
www.cumulusassociation.org

All content remains the property of authors,
editors and institutes

ISBN 978-958-774-912-0
ISSN 2490-046X

**Publications in Cumulus
Conference Proceedings Series**

01/17	Kolding, REDO
02/17	Bengaluru, Letters to the Future
03/18	Paris, To get there: designing together
04/18	Wuxi, Diffused Transition & Design Opportunities
05/19	Rovaniemi, Around the Campfire- Resilience and Intelligence
06/19	Bogota, The Design After

Universidad de los Andes | Vigilada Mineducación.
Reconocimiento como universidad: Decreto 1297 del 30 de mayo de 1964.
Reconocimiento de personería jurídica: Resolución 28 del 23 de febrero de 1949, Minjusticia.
Acreditación institucional de alta calidad, 10 años: Resolución 582 del 9 de enero del 2015, Mineducación

THE DESIGN AFTER

Cumulus Conference Proceedings Bogota 2019

Cumulus Conference
Proceedings Series

Cumulus Association of
Universities and Colleges
of Art, Design and Media

Bogota 2019

MESSAGE FROM THE DEAN	10
MESSAGE FROM THE PRESIDENT OF CUMULUS	12
KEYNOTES	14
CONFERENCE THEMES	17
REVIEWERS	18

CONTENTS

BUILDING NEW IDENTITIES WITH BATIK Martin John Bonney	21
SENSING IGOLI: APPLYING TYPOLOGICAL ACTIVITY SYSTEM MODELS IN THE DESIGN OF INNOVATIVE AND APPROPRIATE URBAN TECHNOLOGIES Terrence Fenn, Angus Donald Campbell	34
RESEARCH VIDEO: AUDIOVISUAL ETHNOGRAPHY AND BEYOND Léa Klaue	48
AQUA_MATICES: INTERACTIVE AQUAPONICS FOR EXPERIENCE-BASED LEARNING IN STEAM Yeferzon Alexander Ardila, Veronica Akle Alvarez, María de los Ángeles González, Freddy Zapata Vanegas, Johann Faccelo Osma, Martha J. Vives Florez	50

AN EDUCATIONAL INTERACTIVE DASHBOARD FOR AGROLAB'S AQUAPONIC SYSTEM

Pablo Figueroa, Leonardo Parra,
Freddy Zapata 64

SHANGHAI (1912-1949): VALUE OF CONSUMER GOODS IN THE URBAN-RURAL INTERACTION RELATIONSHIP

Yanghuan Long, Qiang Wang, Chen Fan 76

INSPIRATIONS FROM JIANGNAN CLASSIC GARDEN TO CITY LANDSCAPE DESIGN REQUIREMENTS

Shu Xu, Weimin Guo 89

SENSE-MAKING STRATEGIES IN ICT ADOPTION FOR RURAL POPULATION IN THE DOMINICAN REPUBLIC

Azalya Latorre 103

RURAL COMMUNITY PARTICIPATION DIGITAL PLATFORM

Carlos Cobreros, María Elena Melón,
Eduardo Rosado, Nohemi Lugo,
Mariana Maya 115

INSIGHTS FROM A DESIGN-LED INQUIRY ABOUT RURAL COMMUNITIES IN BRAZIL

Caio Werneck, Javier Guillot, Bruno
Paschoal 125

HYBRID LANDSCAPES: EXCHANGES BETWEEN ART, DESIGN AND TECHNOLOGY IN THE URBAN INTERFACE

Facundo Colantonio 127

FINDING A NEW COMMONS: ARCHITECTURE'S ROLE IN CULTURAL SUSTAINABILITY FOR JAPAN'S SHRINKING REGIONS

Julia Nakanishi, Lola Sheppard (Thesis
Supervisor), Jane Hutton (Thesis
Committee) 140

AGROLAB: A LIVING LAB IN COLOMBIA FOR RESEARCH AND EDUCATION IN URBAN AGRICULTURE

Freddy Zapata Vanegas, Giacomo
Barbieri, Yeferzon Alexander Ardila,
Veronica Akle Alvarez, Johann
Faccelo Osma 142

DESIGNING RURAL EXPERIENCES THROUGH SERVICE DESIGN METHODS AND STRATEGIC SCENARIOS: TWO CASE STUDIES IN JALISCO, MEXICO

Ruth Maribel León Morán, David
Sánchez Ruano, Roberto Iñiguez Fores 156

PLANT-DRIVEN DESIGN AND PHYTOTECHNOLOGY TO IMPROVE THE BUILT ENVIRONMENT

Laura Dominici, Elena Comino,
Pier Paolo Peruccio 169

SOCIAL DESIGN FOR TECHNOLOGY TRANSFER: AN EXPERIENCE IN RURAL COLOMBIA

Juan Manuel España, Fabio Andrés
Téllez 182

SOMEWHERE, NOWHERE, ANYONE, EVERYONE

Is it possible for designers to learn and design along with small communities?

CITIZENSHIP IN DESIGN EDUCATION AS A TRANSFORMATIVE LEARNING PROCESS. ID TI	
Massimo Santanicchia	194
CONTROVERSIAL-ORIENTED STORYTELLING AS A METHOD FOR DEALING WITH WICKED PROBLEMS	
Nicole Simonato, Guilherme Meyer	207
MOVEMENT AND PLACE-MAKING IN A MONSOON TERRAIN	
Deepta Sateesh	221
PARTICIPATORY DESIGN THROUGH JEWELLERY PROTOTYPES: SCANDINAVIAN DESIGNERS AND ZIMBABWEAN VILLAGE ARTISANS	
Margaret Rynning	223
PEDAGOGICAL STRATEGIES FOR SOCIAL IMPACT DESIGN, DESIGNING WITH THE POPRUA	
Susan Melsop, Juliana Bertolini	236
A RESEARCH AND TEACHING PROJECT FOR THE MARTESANA DISTRICT	
Laura Galluzzo, Claudia Mastrantoni, Ambra Bori, Margherita Rasio, Jixiang Jiang	248
CARPAS SOCIALES: A STRATEGY FOR SOCIAL INNOVATION IN FENICIA THROUGH AQUAPONICS	
Laura Amaya, Freddy Zapata, Catalina Ramirez	260
INDIGENOUS ANCESTRAL IMAGINARIES AND MATERIAL TRANSFORMATION FROM AN ANTHROPOLOGIC DESIGN APPROACH	
Ricardo Labra Mocarquer, Christian Basáez Villagrán	274
ARTISANS AND DESIGNERS: SEEKING FAIRNESS WITHIN CAPITALISM AND THE GIG ECONOMY	
Raphaële Chappe, Cynthia Lawson Jaramillo	286
SABER DEL MONTE: DESIGN AS A CATALYST FOR SOCIO-ECOLOGICAL RECIPROCITY	
Lina Lopez-Lopez, Miguel Navarro-Sanint, Natalia Cardenas-Cardenas	288
PERCEIVED DESIGN VALUE THROUGH THE LENS OF GENERATION Z	
Aija Freimane	302

FICTION AND DE-INNOVATION

The focus of the track is the articulation between world-making exercises and design methods that reformulate The identity of design.

DRESS ACTION: AN ALTERNATIVE FOR POSTFASHION	
Corneliu Dinu Tudor Bodiciu	315
EVERYONE DESIGNS IDENTITY AND DETERMINISM IN THE DIGITAL AGE	
Miguel Lopez Melendez	326
'PATADESIGN: A PEDAGOGICAL EXPERIMENT ON DESIGN OF EXCEPTION, ABSURD ARTIFACTS AND IMAGINARY INTERFACES	
Isabella Brandalise, Henrique Eira	339
DESIGNING FASHION FICTIONS: SPECULATIVE SCENARIOS FOR SUSTAINABLE FASHION WORLDS	
Amy Twigger Holroyd	341
BLACK PANTHER'S UTOPIAN PROJECT: THE INNOVATIVE POTENTIAL OF FICTION AND SPECULATION BY NON-ARCHITECTS	
Fiona Kenney, Vaissnavi Shukl	352
RETHINKING THE PLACE OF NARRATIVES IN DESIGN FICTION: A GAP BETWEEN POLICIES AND THE REAL APPROACH TO VICTIMS	
Mónica Paola Peña Zambrano	354
DESIGN FICTION: LATERAL THINKING FOR SOCIAL DESIGN	
David Hernández Falagán	363
DESIGNING GOVERNANCE IN THE FOURTH INDUSTRIAL REVOLUTION	
Paula Riveros Tovar	372
RE-CONTEXTUALISING THE DESIGN PROCESS IN FASHION EDUCATION	
Shalini Gupta, Varun Goel	381
NATIONAL MEMORY AND DESIGN OPPORTUNITIES: PATTERN DESIGN OF TRADITIONAL CHINESE FESTIVAL COSTUMES	
Kunyuan Li, Hui'e Liang	393
TECHNOLOGIES FOR INTROSPECTION: SPECULATIONS ABOUT THE RELATIONSHIP BETWEEN SUBJECT, PERCEPTION AND TECHNOLOGY	
Laura Catalina Junco Gómez	406
PROVOCATIVE PLAYGROUND: CO-DESIGN OF URBAN SPACES IN CONTEXTS OF HIGH DEGREE OF MARGINALIZATION	
Mariana Maya, Carlos Cobreros, Gustavo Peñaloza	417
POSTHUMANWEAR EXPLORING POSTHUMAN IDENTITIES AND AESTHETICS THROUGH DESIGN FICTION	
Juan Carlos Guevara Verjel	428
RE-THINKING THE DESIGN ROLE: EXPERIMENTING NEW NARRATIVE & RHETORIC DESIGN METHODS	
Valeria Maria Iannilli, Antonella Valeria Penati, Alessandra Spagnoli	438
THE EXTENDED PRAXIS OF DESIGN: TOWARDS A CHARACTERIZATION OF THE ADVANCED DESIGN CULTURES	
Roberto Iñiguez Flores, Ruth M. León Morán, Flaviano Celaschi, Elena María Formia	449

BIODIVERSITY-DRIVEN DESIGN

Is it possible for science and design to question how their knowledge can be better integrated to solve real world problems?

HISTORY MAY LEAD TO FUTURE: HOW CHINESE FIVE ELEMENTS THEORY HELP TO IMPROVE PRODUCTS' EMOTIONAL DURABILITY	
Ruimin Hao, Jiawei Zou	500
BATRACHARIUM – AN IN SITU PARTICIPATORY CONSERVATION AND EDUCATION PROGRAMME FOR AMPHIBIANS	
Gururaja Kotambylu Vasudeva	511
EXPLORING THE BENEFITS OF NATURALLY COLORED COTTON FOR FUTURE DESIGN SOLUTIONS	
Sharda Nautiyal, Sakshi Babbar Paul	520
BUILDING A BIODESIGN CURRICULUM	
Jenifer L. Wightman, Jane Pirone	532
SYMBIOGENESIS-BASED DESIGN: A NOVEL METHODOLOGICAL APPROACH TO DESIGN BASED ON COOPERATION AND INTEGRATION	
Alejandro Durán Vargas, Lorena O'Ryan Cuevas	554
TRANSFORMING AGRICULTURE THROUGH URBAN PRODUCTION METHODOLOGIES WITH THE SUPER POTATO	
Elizabeth Jamie Dellheim, Stephen Enrique Bruque Coral, Laura Andrea Cabrera Villamizar, Pablo Llinás Tono	568
BIOMINING: AN APPROACH FROM BIODESIGN IN SEARCH FOR AN ECOLOGICAL EQUILIBRIUM	
Lina Gisell Aranzalez Rodriguez, Brillyt Carolina Quimbayo Gutiérrez, Carolina Páez Vélez	579
SENSING NATURE: EXPERIENCE DESIGN FOR LEARNING THE INTERPLAY BETWEEN MATERIALS AND EMOTIONS	
Sara Lucía Rueda Mejía	589
PROTOTYPE OF A SELF-SUFFICIENT BIOFABRICATION PROTOCOL FOR REMOTE TERRITORIES	
Aníbal Fuentes Palacios, Carolina Pacheco Glen, Adriana Cabrera Galindez, Alejandro Weiss Munchmeyer, María José Besoain Narvaez	601

WALKING IN THE AGE OF ANTHROPOCENE: AN INTERDISCIPLINARY LEARNING EXPERIMENT FOR A SUSTAINABLE FUTURE	
Fan Feng	461
TRANSDISCIPLINARY COLLABORATION MEDIATED BY DESIGN: AN INITIATIVE FOR RURAL ADAPTATION TO CLIMATE CHANGE	
Luis Beltran-Forero, Fabio Andrés Telléz	472
TECHNO-AESTHETIC SPACES OF FICTION	
Karen Aune	486
BIOFORM – LEARNING AT THE INTERSECTION OF SCIENCE AND DESIGN	
Damian Palin, Sam Russell, Ferdinand F. E. Kohle, Enda O'Dowd, S. Yeşim Tunalı Flynn	498

DESIGN AND COUNTERCULTURE

What is the role design could play in creating new production models or economic systems?

WALKING BACKWARDS INTO THE FUTURE: USING INDIGENOUS WISDOM WITHIN DESIGN	
Nan O'Sullivan	606
A CONTEMPORARY URBAN HUMANISM: THE URBAN SPACE AS CULTURAL FRAMEWORK FOR PARTICIPATIVE ARCHITECTURE, GRAFFITI IMAGE AND URBAN GENRES	
Omar Campos Rivera	615
THE CREATION OF A DIGITAL PUBLICATION ABOUT GENDER AND DIVERSITY FOR EARLY CHILDHOOD	
Débora Falleiros Gonzalez	627
COLLABORATION AS A FORM OF COUNTERCULTURE	
Dickson Adu-Agyei, Finzi Edward Saidi, Jabu Absalom Makhubu	639
SUSTAINABLE DESIGN AS ANTI-FASHION	
Daniela Monasterios-Tan	651
DESIGN AGAINST WAR. HOW CAN DESIGN SUPPORT THE EFFORT TO PREVENT CONFLICT, MITIGATE WAR DAMAGES AND PROMOTE A CULTURE OF CARE?	
Massimo Bruto Randone, Irina Maria Suteu	664

HAND-MAKING AS THE INTERPLAY OF THE PERSONAL AND COLLECTIVE IN DESIGNING TRANSITIONS	
Marysol Ortega Pallanez	675
BOGOTA DUST AND PAPER CITY: A CRITICAL DESIGN EXERCISE THAT EXPLORES CORRUPTION IN TOWN	
Viviana Alejandra Moya Arenas	686
BIO-CURRENCIES: AN ALTERNATIVE TO PAYMENTS FOR ENVIRONMENTAL SERVICES (PES)	
Santiago De Francisco Vela, Miguel Navarro-Sanint, María Belén Castellanos Ramírez, Leidy Lorena Rodríguez Pinto, Catalina Ramírez Díaz	698
SOCIALLY ENGAGED DESIGN AND ART EDUCATION PRACTICES FOR REINVENTING TERRITORIES	
Andréia Menezes De Bernardi, Edson José Carpintero Rezende, Juliana Rocha Franco	700
THE TRANSFORMED SOCIAL FUNCTION OF RELIGIOUS ARCHITECTURE – TAKE “ZHUANGFANG” AS AN EXAMPLE	
Jiaye Chen, Qiang Wang, Lu Ding, Stephen R. Drown, Anran Feng	711
APPLYING HUMAN-CENTERED DESIGN AND BEHAVIORAL ECONOMICS TO DRIVE UPTAKE OF PREP AMONG SEX WORKERS	
Juanita Rodríguez Barón, Dean Johnson	722
CLASSROOM AS RESISTANCE: MICRO-STRATEGIES FOR DESIGN EDUCATION	
Gaia Scagnetti, Nida Abdullah	735
FROM SELF-CARE TO WE-CARE: PRACTICAL TOOLS FOR FIGHTING ORGANIZATIONAL BURNOUT	
Jenny Liu, Hannah Roodman	746
ABRACEMOS LO NUESTRO: ENCOURAGING NEW IDEATION WITH TRADITIONAL PARAGUAYAN TEXTILES	
Andrea Gonzalez Esteche, Melissa Dawson	760
PHOTO-ETHNOGRAPHY AND POLITICAL ENGAGEMENT: STUDYING PERFORMATIVE SUBVERSIONS OF PUBLIC SPACE	
Pablo Hermansen, Roberto Fernández	771

BIBLIOGRAPHY / REFERENCES

- Camelo Avedoy, J. O., & Rodríguez Bautista, J. J. (2018). ¿WHY TEQUILA IS NAMED TEQUILA? AN APPROACH FROM THE REGIONAL ECONOMIC HISTORY. http://www.Ecorfan.Org/Journal/V9n20/ECORFAN_Journal_Mexico_V9_N20.Pdf. Recuperado de <http://dspace.uan.mx:8080/xmlui/handle/123456789/1091>
- Campbell, K., Schwier, R. A., & Kenny, R. F. (2009). The critical, relational practice of instructional design in higher education: an emerging model of change agency. *Educational Technology Research and Development*, 57(5), 645-663. <https://doi.org/10.1007/s11423-007-9061-6>
- de Grammont, H. C. (2004). La nueva ruralidad en América Latina. *Revista Mexicana de Sociología*, 66, 279-300. <https://doi.org/10.2307/3541454>
- Fundación Beckmann. (n.d).Historia. Recuperado 13 de junio de 2019, de <http://www.fundacionbeckmann.org/historia/>
- Mara Rosas-Baños, «Nueva Ruralidad desde dos visiones de progreso rural y sustentabilidad: Economía Ambiental y Economía Ecológica », Polis [En línea, 34 | 2013, Publicado el 22 julio 2013, consultado el 13 junio 2019. URL : <http://journals.openedition.org/polis/8846>
- Martin, R., & Martin, R. L. (2009). *The Design of Business: Why Design Thinking is the Next Competitive Advantage*. Harvard Business Press.
- Modelo Tec21. (n. d.). Recuperado 15 de julio de 2019, de <https://tec.mx/es/modelo-tec21>
- Morgan, E. (2016). *The New European Rurality: Strategies for Small Firms*. Routledge.
- Poggenpohl, S. H. (2015). Communities of Practice in Design Research. *She Ji: The Journal of Design, Economics, and Innovation*, 1(1), 44-57. <https://doi.org/10.1016/j.sheji.2015.07.002>
- Sevaldson, B. (2018). Visualizing Complex Design: The Evolution of Gigamaps. En P. Jones & K. Kijima (Eds.), *Systemic Design: Theory, Methods, and Practice* (pp. 243-269). https://doi.org/10.1007/978-4-431-55639-8_8
- Soto F, Beduschi L., y Falconi F., 2007. Desarrollo territorial rural análisis de experiencias en Brasil, Chile y México. Organización de las Naciones Unidas para la Agricultura y la Alimentación - FAO Oficina Regional de la FAO para América Latina y el Caribe. Consultado en: <http://www.fao.org/3/a-a1253s.pdf> May 2019.
- Stickdorn, M., & Schneider, J. (2012). *This is Service Design Thinking: Basics, Tools, Cases* (1.a ed.). Wiley.
- Wood, A. E., & Mattson, C. A. (2019). Quantifying the effects of various factors on the utility of design ethnography in the developing world. *Research in Engineering Design*, 30(3), 317-338. <https://doi.org/10.1007/s00163-018-00304-2>

PLANT-DRIVEN DESIGN AND PHYTOTECHNOLOGY TO IMPROVE THE BUILT ENVIRONMENT

In post-industrial cities the quality of built environment is partially affected by the high concentration of chemical pollutants in outdoor and indoor spaces. An increasing number of people spend about 90% of their daily time in indoor environment that often has a higher concentration of pollutants than outdoors. The presence of many chemical compounds and the absence of natural elements contributes to reduce the healthiness of indoor spaces and to trigger the Syndrome of Sick Building in occupants. Many researches support that natural ecosystems have a positive effect on human health and other studies show the benefits provided by the application of phytotechnology. This paper discusses the opportunities offered by the application of plant-based solutions to improve the healthiness of built environment (especially the indoor air quality) and to re-establishing a relationship between man and rural spaces, with positive implication on psychological well-being. Phytotechnology includes many techniques to remediate polluted sites or to mitigate effects of anthropogenic activities using plant's metabolism according with technological solutions. In the paradigm shift toward an ecological view, natural ecosystems are considered as a part human society and plants are good indicators of the quality of the environment. This study focuses on the review of ecosystems services provided by plant-based solutions and it also reflects on the inclusion of phytotechnology in design practice for the well-being of people in indoor spaces and more in general in post-industrial cities.

Keywords: plant-driven innovation, nature and human health, healthiness of built environment, phytotechnology, design for sustainable living

Pier Paolo Peruccio

Department of Architecture and Design (DAD)
Politecnico di Torino
pierpaolo.peruccio@polito.it

Elena Comino

Department of Environment
Land and Infrastructure Engineering (DIATI),
Politecnico di Torino
elena.comino@polito.it

Laura Dominici

Department of Environment
Land and Infrastructure Engineering (DIATI),
Politecnico di Torino
laura.dominici@polito.it

INTRODUCTION

Technological developments have brought a substantive revolution in human society. For the first time in the human history, more than half of global population, approximately 55%, is living in urban areas (UN-Habitat, 2011; Carli et al., 2015). Predictions regard the future of human society confirm this trend: the future will be characterized by urbanization (Randers, 2012). Global population is growing fast (United Nations, 2017) and all over the world people are moving from rural areas towards cities with the purpose to find safety and new opportunities for living. The UN-Habitat (2016) estimates that by 2050 about 70% of the population will live in metropolitan areas.

The increasing urbanization affects people's lifestyles and the political agenda that should focus on tackling problems related to the use and consumption of resources and the health of the urban environment. The rapid growth of cities causes environmental degradation, loss of biodiversity and ecosystem services (Harding, 2012). An important aspect of urbanization trend and virtual technology is that people are spending almost 80-90% of their daily time in indoor spaces such as school, home, workplaces and other public spaces (Liu et al., 2019). Outdoor and indoor air quality in the most of cities, with a population more than 1 million, fails to meet World Health Organization guidelines for healthy living (WHO, 2016). Moreover, the concentration of air pollutants in interiors is often higher than in outdoor spaces (Marchland et al., 2006).

In this scenario, the urgency is to undertake a paradigm shift toward an ecological perspective (Capra & Luisi, 2014) of built environment and also of interiors. Benefits provided by parks and green infrastructures in cities are widely discussed in many researches (Suzuki, 2015; Stigsdotter, 2015), while their effectiveness in indoor spaces is still an uncertain topic. This paper focuses on the opportunities provided by technological green, such living wall, to improve indoor air quality. Living

walls are investigated as constructed ecosystems that integrate phytotechnology in interior design practice. The investigation underlines main strengths and problems in applying principles of *nature-centred approach* of phytotechnology in designing not only aesthetically, but also functional indoor green systems. Nature-centred design is a concept recently introduced by Van der Ryn (2013) and Tarazi et al. (2019), that supports the Human-centred design according to the urgencies expressed by the Anthropocene. It adopts a more holistic and ecological view to the design practice and it uses design research tools to investigate complex problems.

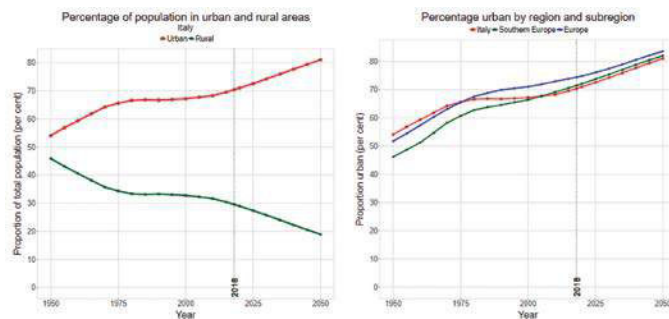
CHARACTERISTICS OF AIR QUALITY IN INDOOR SPACES AND CONSEQUENCES ON HUMAN HEALTH

In recent years, increasing attention has been focused to improve the *indoor environmental quality* (IEQ) and the comfort of interiors. The IEQ involves a huge set of parameters that includes light intensity, visual and acoustical aspects, thermal comfort and air quality (Bluyssen, 2009a). Indoor air quality (IAQ) is an important aspect of IEQ because it causes complications on human health and it has also consequences on occupant's performances (Ataroldi et al., 2018). IAQ is characterized by the concentration of specific compounds that cause indoor air pollution and it also depends by the features of buildings and by the habits of occupants. It can be distinguished in chemical and biological pollution based on the emission source. This investigation considers only chemical compounds that influence indoor air pollution and interaction of plants with them. Bluyssen (2009b) asserts that IAQ can be integratively approached from three perspectives: indoor air of the space, sources that release harmful compounds and human point of view. In addition to these, the outdoor air pollution has a serious influence on increasing the concentration of specific compounds in indoor air. Moreover, the aim to reduce the energy consumption for mechanical air ventilation systems encourages to investigate alternative solutions to improve IAQ and IEQ.

Indoor air perspective and sources of emission: regulations and recommendations

Indoor air is often expressed in terms of ventilation rate and concentration of specific compounds. The World Health Organization (WHO) (2009; 2010) selected a list of chemical compounds and defined general guidelines for their concentration limits and their effects on human health (Table 1). In addition to these, Ozone (O_3), Carbon dioxide (CO_2) from human metabolism, Particulate matter (PM_{10} and $PM_{2.5}$) from ambient pollution and Total Volatile Organic Compounds (TVOC) can affect indoor air

Figure 1. The first graph shows urban (red line) and rural (green line) population in Italy as a percentage of the total population, 1950 to 2050. The second graph shows proportion of urban population in Italy (red line) as compared to the Southern Europe (green line) and Europe (blue line). The proportion is expressed as a percentage of the total population, 1950 to 2050. Data from the United Nations DESA Urbanization Prospects (2018).



quality. In many countries official regulation regards the presence of air chemical pollutants is still missing and general standards are not enough to meet the satisfaction of occupants (Ferrero, 2018). Many of these compounds can be registered in the most of indoor environment because they are released by furniture, paints, cleaning products, electronic device, building materials (Yangpen et al., 2018) and their concentration also depends by human activities, such as cooking. The evaluation of outgassing rate is a complex process because it depends by many factors such as the content of volatile compounds and solvents in the indoor air, and by the age and status of materials.

CHEMICAL COMPOUND	CONCENTRATION LIMITS	SOURCE OF EMISSION AND UTILIZATION	CANCEROUS FOR HUMANS
Benzene (C ₆ H ₆)	6 x 10 ⁻⁶ µg/m ³ (UR/lifetime)	Paints, building materials, tobacco, heating and furniture	Group 1
Carbon monoxide (CO)	10 mg/m ³ (8 hours)	Combustion in O ₂ deficit condition	-
Nitrogen dioxide (NO ₂)	40 µg/m ³ (year)	Combustion	-
Formaldehyde (CH ₂ O)	0.1 mg/m ³ (30 minutes)	Furniture in chipboard, household cleaning products, paints, heating and electronic components	Group 1
PAHs and C ₂₀ H ₁₂	8.7 x 10 ⁻⁵ ng/m ³ (UR/lifetime)	Petroleum refining	Group 1
Trichloroethylene (TCE)	4.3 x 10 ⁻⁷ µg/m ³ (UR/lifetime)	Industrial solvent	Group 1

Table 1. List of some indoor air pollutants, their concentration limits (WHO, 2010), main sources of emission and levels of carcinogenicity for humans (WHO, IARC, 2018).

The issue concerns the release of harmful chemical compounds by adhesive in plywood, fiberboard and particleboard furniture and by many other household products, such as textiles, is very relevant in residential-typical conditions (Salthammer, 2019). For potential hazards on human health due to high concentrations of formaldehyde, many important furniture companies are moving toward the use of glue, adhesive, resins, painting and finishing without harmful chemical compound (IKEA, 2018). Synthetic filters of Heating, Ventilation and Air Conditioning systems can also release formaldehyde at the room temperature of 20°C and 80% of relative humidity.

Human health implications

Human perspective regards IAQ reflects the effect on health and wellbeing of exposure to chemical pollutants in indoor air. In comparison to the great importance that ambient (outdoor) air pollution in urban areas has reached in last decades, IAQ does not have the same relevance in political and environmental agendas. Even though, the WHO (2018) established that 3.8 million people a year die prematurely because of exposure to harmful compounds in indoor environments. High concentrations of chemical pollutants and of VOCs contribute to causing the *Sick Building Syndrome* (SBS) and the *Multiple Chemical Sensitivity Syndrome* in occupants. They occur with a set of health problems, firstly respiratory problems, that affect working and learning performances especially in young people and children (Kishi et al., 2018).

PHYTOTECHNOLOGY: FROM ENVIRONMENTAL APPLICATIONS TO INTERIOR OPPORTUNITIES

Concerning environmental issues, the concept of phytotechnology means a huge set of techniques and applications that use plant for providing non-invasive solutions, including phytoremediation and bioremediation processes. It is the use of vegetation to remediate, contain or prevent contaminants, and add nutrients, porosity and organic matter (Kennen & Kirkwood, 2015). Phytotechnology is based on ecological principles and living systems mechanism and it is included in *ecotechnology* techniques (Aida, 1995). It is an interdisciplinary field of study that involves discipline as engineering, planning, design and botany to implement on-site solutions. Phytotechnology applications are successfully tested on soil, groundwater and wastewater management, while in the treatment of air, especially for indoor applications, development of phytotechnologies to remove airborne pollutants is just beginning (Henry et al., 2013).

It is necessary to make a distinction between the term *phytoremediation* and *phytotechnology*. The first concept describes the degradation and/or removal of a contaminant from a polluted site by a specific plant or group of plants. While phytotechnology also includes all plant-based solutions, such as green walls,

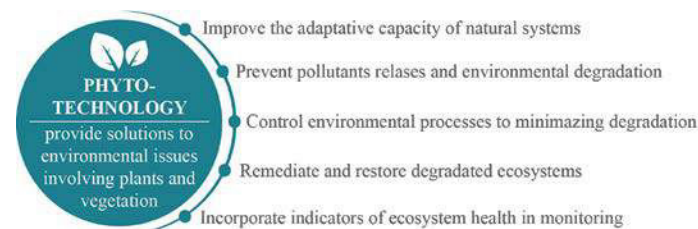


Figure 2. Main phytotechnology application.

green roofs, bioswales and constructed wetlands, to remediate or mitigate an ecological problem (Kennen & Kirkwood, 2015). Phytotechnology can be described as nature-centred approach to manage environmental issues which considers living systems as fundamental part of human society, including cultural aspects, and public health.

Phytotechnology uses opportunities provided by plants' mechanisms contributing in remediating contaminants from soil, water and air medium. Generally, the use of plants in contrasting effects of pollutants involves more than one of following physiological processes (Table 2) that are complementary for the entire phytoremediation. In case of low levels of contaminants concentration, these mechanisms are spontaneously used by vegetation in the process of *natural attenuation*.

Table 2. Plants' mechanisms and their principal applications in the treatment of soil, water and air.

NAME OF PLANT MECHANISM	ORGANIC/INORGANIC CONTAMINANTS	MECHANISM DESCRIPTION	APPLICATION
Phytodegradation	Organic	Plant uptakes contaminants and breaks into non-toxic metabolites	Soil, Water, Air
Rhizodegradation (plant assisted bioremediation/ degradation)	Organic	Roots exudates and/or the soil microbiology in the root zone break down contaminants	Soil, Water, Air
Phytovolatilization	Organic/Inorganic	Plant uptakes pollutants and release them into the atmosphere as gas	Soil, Water, Air
Phytometabolism (or phytotransformation)	Organic/Inorganic	Inorganic elements (as N, P, K) and organic metabolites produced by phytodegradation are metabolized and incorporated in plant's biomass	Soil, Water, Air
Phytoextraction	Organic/Inorganic	Plant uptakes pollutants and move them into plant parts. For organics, it is coupled to phytodegradation process	Soil, Water, Air
Phytohydraulics	Organic/Inorganic	Plant's roots ability to stop migrating plumes	Water
Phytostabilization (or phytosequestration/ phytoaccumulation)	Organic/Inorganic	Plant holds contaminants in place, and it does not move off site. Contaminants are made less bioavailable.	Soil, Air, Water
Rhizofiltration	Organic/Inorganic	Roots filter out pollutant from water	Water & Soil

In the application of phytotechnology for the treatment of air contaminant, plants take advantage of the characteristic of being a *colony* for microbes. Phyllosphere (Wei et al., 2017; Bringel & Cou  , 2015) and rhizosphere (Dela Cruz et al., 2014; Moya et al., 2018), plant's leaves (cuticle and stomata) and roots structure and their associated microbiota, cover an important role in the interaction with chemical compounds (Agarwal, 2019). Phytotechnology air for organic pollutants treatment provides great opportunities in terms of *field applications* and *relative remediation time* (Kennen & Kirkwood, 2015).

General overview on laboratory and field testing of indoor air phytoremediation ability

The attention paid to the capacity of plants to uptake and degrade contaminants from indoor air raised in the 1980s with pioneer studies successfully conducted by NASA on benzene, formaldehyde and trichloroethylene (Wolverton et al., 1989). Afterwards, many other studies were conducted to test in laboratory potted plants' phytoremediation ability and their efficiency (Righetto, 2018; Yang et al., 2009). Based on studies of Wolverton et al. regard plants selection, many species of plants were tested and compared in controlled and sealed chamber experiments. In this condition, parameters such as duration of testing, light intensity, humidity, temperature and concentration of the contaminants are strictly controlled and monitored, unlike what happens in real context. Plants degrade chemical compounds through respiration and photosynthesis by leaf surface absorption and relevant results were also obtained analysing rhizosphere (plant's roots and microorganisms) phytoremediation ability. Significant results are achieved in the phytoremediation of indoor airborne particulates, PM₁₀ in particular, (Pegas et al., 2012; Soreanu et al., 2013); of VOCs (Dela Cruz et al., 2014), and of NO₂ and CO.

In on-site testing, the main problems regard the great variability of above parameters in real context conditions. The efficiency of plant-based applications depends by indoor environmental features, also regard the number of occupants and their habits, by the plant's specie, by total plant's leaf area and by plant's physiology in relation to the condition of surrounding environment. Moreover, limited spaces available in interiors is a main driver that limits an effective application of plants with air remediation purpose. In recent investigations (P  rez-Urrestarazu et al., 2016; Tudiwer & Korjenic, 2017; Abdo et al., 2019) indoor vertical green systems are tested with the purpose to evaluate their performance in improving IAQ and IEQ, especially regard CO₂ sequestration and regulation of relative humidity and temperature. Green wall system is a consolidated technology for outdoor application, but its benefits as functional

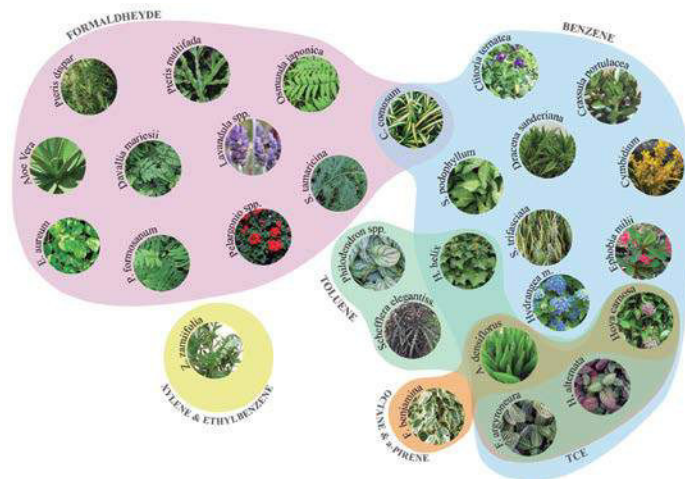


Figure 3. List of most tested ornamental plants for indoor environment (Agarwal et al., 2019).

green technology for indoor environment are almost unknown. Vertical green system (also known as living wall system) is a valid solution to increase the number of plants and the total leaf area in indoor spaces. Many studies (Pérez-Urrestarazu et al., 2016; Moya et al., 2018; Petit et al., 2018; Abdo et al., 2019) are testing the performances of active living wall systems (biofilter green wall systems) to investigate air bioremediation ability of plant's rhizosphere (especially regard VOCs treatment).

Functional living wall systems, not only aesthetically, can be interesting applied in public and shared spaces, such as schools, offices and co-working spaces. Positive effects on occupant's education, awareness, comfort satisfaction, psychological wellbeing, working productivity and learning skills of indoor greenery practice are well documented, while indications to improve IAQ are still uncertain, especially for traditional living wall systems. However, studies conducted on indoor phytoremediation published lists of plant species that have achieved good performances (Figure 3). The most of ornamental plant species analysed are shade-loving and with rich foliage (green leafy part) that produce less pollen and bloom to avoid the risk of allergic or negative response in occupants.

Opportunities and constraints in applying phytotechnology to real context

Complexity in the nature and sources of air pollutants and of other environmental features requires that plant-based solutions are site-specific design processes. There is not a unique definition of a clear methodology for designing living wall systems that is valid for all indoor environment: plant species, substrate of cultivation, microbe and structure that support the entire

OPPORTUNITIES

- ✓ Natural, passive, solar energy-driven and methods to regenerate and clean up built environment
- ✓ Non-invasive solution and adaptable for specific site
- ✓ Possible application for treating a wide range of contaminants
- ✓ Multidisciplinary approach that combine chemistry, physics and biology with design and technical disciplines
- ✓ Well-accepted technologies for aesthetical and visual value
- ✓ Pollution prevention and mitigation effect
- ✓ Plant species for monitoring and assessing the ecosystem health

SECONDARY OPPORTUNITIES

Community use: involvement of stakeholders and people in planning stages

Educational use: classroom and living-lab experiences for increasing awareness and knowledge of plant world

CONSTRAINTS

- ✓ Some contaminants cannot be remediated by phytotechnologies
- ✓ Contaminant's level is too high for plant-based solutions application
- ✓ The elongated timescale to be effective (especially in soil and water)
- ✓ Fluctuation and vulnerability of natural systems (reactions to environmental and climate conditions)
- ✓ Context-based application: it depends by the characteristics of that specific site
- ✓ Some applications are quite expensive to be really effective and to maintain them (range cost for 1m² of green wall: 250 - 600 euro)
- ✓ Boundaries of systems are not well defined, especially in case of atmosphere (outdoor air) in urban areas

Figure 4. Opportunities and constraints in the application of phytotechnologies for the treatment of chemical compounds and positive implications at the community level.

living wall should be quite different for each environment. The selection of plant and design method occurs after a specific characterization of the context and of users/occupants. This step is particularly relevant to identify users' needs, their habits and expectations regarding the usability and interactions level with the vertical green system. Needs expressed in school environments are different from co-working spaces, private offices and healthcare buildings: some technical measures are essential in specific context to maintain the safety of users. The application of phytotechnology mechanism in indoor environment through the design of living wall systems presents interesting

opportunities but constraints are also prominent (Figure 4). For example, costs for the entire life cycle of living walls, including costs for maintenance, could affect decision making especially in public buildings (e.g. schools). Some companies, such as Terapia Urbana (Sevilla, Spain), Naava (Helsinki, Finland) and Junglefy (Banksmeadow, Australia), offer design solutions and products to build aesthetically efficient living walls applying different technologies. The ongoing and future challenges investigate ways and technologies to increase the effectiveness of indoor living walls for the improvement of air quality and indoor environment. It is possible by investigating plant configurations, cultivation substrates and low energy solutions to improve the phytoremediation ability of indoor living walls and to reduce costs for operations, installation and maintenance. Living wall technology is an open research field investigated in collaboration with research groups and universities.

DESIGN WITHIN LIVING SYSTEMS: TOWARDS AN INTEGRATIVE APPROACH IN DESIGN PRACTICE

The increasing attention on sustainability requires a paradigm change in design practice towards an ecoculture thinking that focuses on designing living spaces looking at nature as a model (Benyus, 1998). In recent years, the cross-disciplinary approach of *Biodesign*, the practice of design with biology, ecology and engineering, and the *Biophilic Design* (Kellert et al., 2008; Sanchez et al., 2018; Xue et al. 2019; Abdelaal, 2019) that improves health and well-being in built environment have become relevant in the panorama of design. Biodesign goes beyond *biomimicry* and it refers specifically to the involvement of living organisms and their principles as an essential component for functioning (Myers, 2018). Phytotechnology can be defined as a nature-centred approach that considers plants as partners in improving built environment and containing or remediating harmful impacts caused by human activities. Opportunities provided by plants for the improvement of IAQ should be involved in the practice of biophilic design supported by technical and scientific knowledge. The nature-centred design strategy must consider also to sustain and support plants' life in unusual indoor context for growing, far from natural environment. This aspect and the necessity of reducing the energy for lighting and for mechanical air ventilation, often used in biofilter green walls, are main challenges in phyto-design for improving the IAQ. In order to achieve good air phytoremediation performance, plants must be in good health and design must support and promote flourishing growth providing proper technical equipment. Living wall systems can be described as constructed ecosystem, integrated in urban environment, which must support plant.

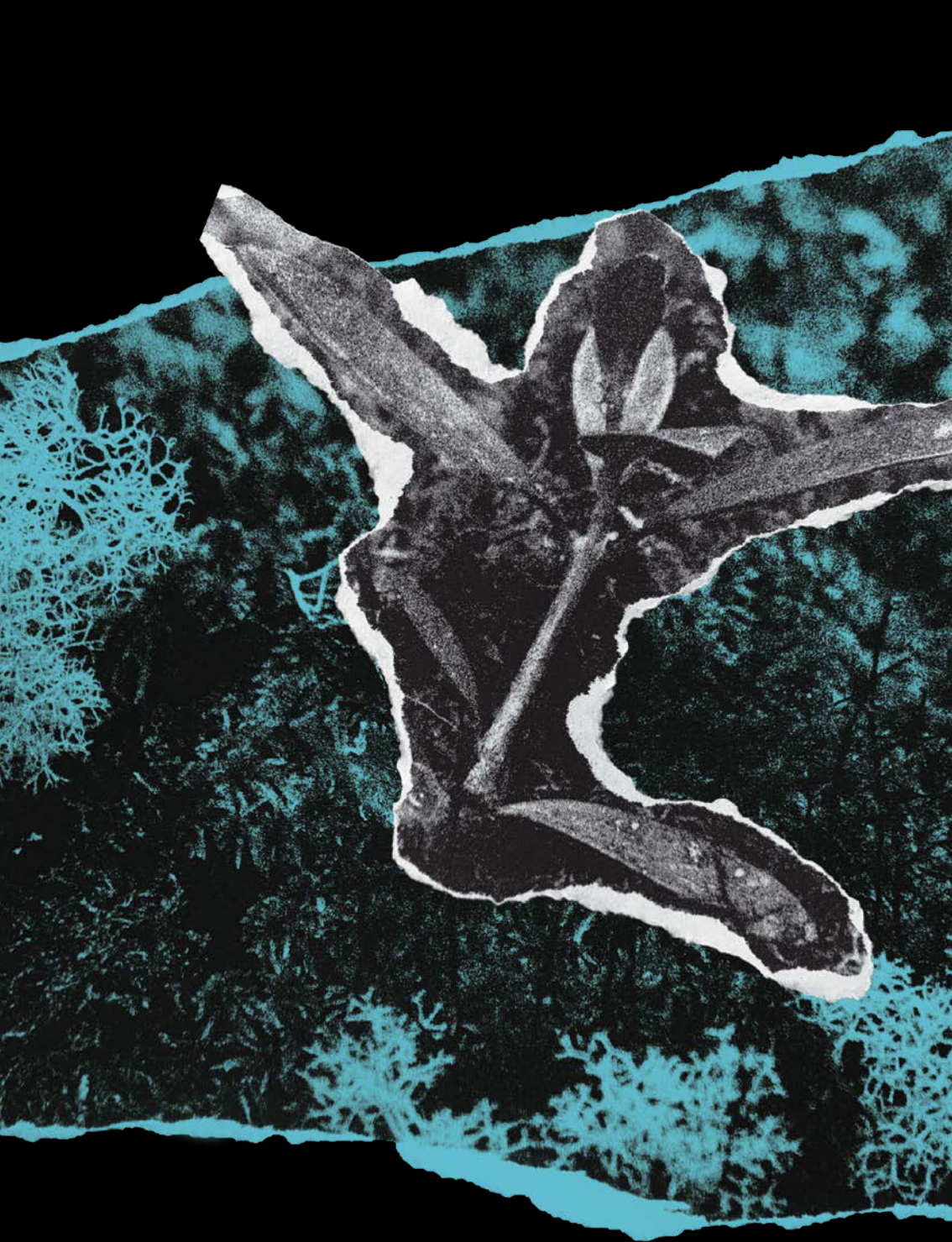
CONCLUSIONS

The urgency to improve the environmental quality and sustainability in urban areas encourage to take into consideration natural systems and their properties. The main challenge is to define technical and ecological indications for including nature ecosystems in the design of built environment towards a *regenerative* approach. Humans depend completely from the presence of plants on the Earth's surface for food, soil regeneration, provision of oxygen and more in general for the mitigation of climate conditions. Plants are essential for human life and they should be considered as strong partners in development processes. It requires to move from an anthropocentric view of life towards a systemic perspective and a long term attitude understanding the important role of living systems in restorative design practice. In many cases, they have already solved issues to improve resources efficiency and their regenerative ability (Mancuso & Viola, 2015; Bruni, 2015). Taking into consideration the strong increase in urban population, plants are essential partners to reestablish the important relationship between humans and natural environment in metropolitan areas.

Plant-driven design and nature-centred design that includes phytotechnology's opportunities show interesting way to improve the quality of built environment. As dynamic systems and living organisms, plants interact with the surrounding and intelligently responds to its stimulations, adapting themselves to the context. Although plants are among the oldest organisms in the world, they remain largely unknown. For an effective and functional application of plants' intelligence and of their living mechanism in indoor spaces, phyto-design practice should promote the transfer of knowledge between disciplines to define the best site-specific solutions.

BIBLIOGRAPHY / REFERENCES

- Abdelaal, M.S. (2019). Biophilic campus: An emerging planning approach for a sustainable innovatio-conducive univerisity. *Journal of Cleaner Production*, 215, 1445-1456.
- Agarwal, P., Sarkar, M., Chakraborty, B., Banerjee, T. (2019). Phytoremediation of Air Pollutants: Prospects and Challenges. In V.C. Pandey and K. Bauddh (Ed.) *Phytomanagement of Polluted Sites: Markets Opportunities in Sustainable Phytoremediation*. Elsevier.
- Aida, S. (1995). An introduction to ecotechnology and its application to AIES project. *Pattern Recognition*, 28, 1455-1458.
- Ataroldi, Z., Karimyan, K., Gupta, V.K., Abbasi, M., Moradi, M. (2018). Evaluation of indoor air quality and its symptoms in office building – A case study of Mashhad, Iran. *Data in Brief*, 20, 74-79.
- Benyus, J.M. (1998). Biomimicry. *Innovation inspired by Nature*. William Morrow.
- Bluyssen, M.P. (2009a). *The Indoor Environment Handbook: how to make buildings healthy and comfortable*. RIBA Publishing.
- Bluyssen, M.P. (2009b). Towards an integrative approach of improving indoor air quality. *Building and Environment*, 44, 1980-1989.
- Bringel, F., Couée, I. (2015). Pivotal roles of phyllosphere microorganisms at the interface between plant functioning and atmospheric trace gas dynamics. *Frontiers in Microbiology*, 6.
- Bruni, R. (2015). *Erba volant. Imparare l'innovazione dalle piante*. Codice Edizioni.
- Capra, F, Luisi, P.L. (2014). *The Systems View of Life*. Cambridge University Press.
- Carli, E., Giarizzo, E., Burrascano, S., Alòs, M., Del Vico, E., Di Marzio, P., Facioni, L., Gianicola, C., Mollo, B., Paura, B., Salerno, G., Zavattero, L. (2018). *Using vegetation dynamics to face the challenge of the conservation status assessment in semi-natural habitats*. Rendiconti Lincei. Scienze Fisiche e Naturali.
- Cox, D.T.C., Shanahan, D.F., Hudson, H.L., Fuller, R.A., Gatson, K.J. (2018). The impact of urbanisation on nature dose and the implications for human health. *Landscape and Urban Planning*, 179, 72-80.
- Dela Cruz, M., Christensen, J.H., Thomsen, J.D., Müller, R. (2014). Can ornamental potted plants remove volatile organic compounds from indoor air? – a review. *Environmental Science and Pollution Research*.
- Ferrero, D. (2018). *Cause e conseguenze dell'inquinamento chimico negli ambienti di studio*. Thesis in Engineering for Environment and Land, Politecnico di Torino.
- Harding, S. (2012). La natura soltanto nei parchi. In J. Randers *Scenari globali per i prossimi quarant'anni. Rapporto al Club di Roma (pp 157-159)*. Edizioni Ambiente.
- Henry, H.F., Burken, J.G., Maier, R.M., Newman, L.A., Rock, S., Schnoor, J.L., Suk, W.A. (2013). Phytotechnologies – Preventing Exposures, Improving Public Health. *International Journal of Phytoremediation*, 15(9), 889-899.
- IKEA. (2018). Ranking retailers on toxic chemicals. <https://retailerreportcard.com/retailer/ikea/>
- Kellert, S.R., Heerwagen, J.H., Mador, M.L. (2008). *Biophilic Design: the theory, science and practice of bringing buildings to life*. Wiley.
- Kennen, K., Kirkwood, N. (2015). PHYTO. *Principles and resources for site remediation and landscape design*. Routledge.
- Kishi, R., Ketema, R.M., Bamai, Y.A., Araki, A., Kawai, T., Tsuboi, T., Saito, I., Yoshioka, E., Saito, T. (2018). Indoor environmental pollutants and their association with sick house syndrome among adults and children in elementary school. *Building and Environment*, 136, 293-301.
- Liu, Z., Li, W., Cheng, Y., Luo, Y., Zhang, L. (2019). Review of energy conservation technologies for fresh air supply in zero energy buildings. *Applied Thermal Engineering*, 148, 544-556.
- Mancuso, S., Viola, A. (2015). *Verde Brillante. Sensibilità e intelligenza del mondo vegetale*. Giunti Editore.
- Marchland, C., Bulliot, B., Le Calvé, S., Mirabel, P. (2006). Aldehyde mesurement in indoor environments in Strasbourg (France). *Atmospheric Environment*, 40, 1336-1345.
- Myers, W. (2018). *Biodesign: nature, science, creativity. Revised and expanded edition*. MoMA.
- Moya, T.A., van den Dobbelsteen, A., Ottelé, M., Bluyssen, P.M. (2018). A review of green systems within the indoor environment. *Indoor and Built Environment*, 28(3), 298-309.
- Pegas, P.N., Alves, C.A., Nunes, T., Bate-Epey, E.F., Evtugina, M., Pio, C.A. (2012). Could houseplants improve indoor air quality in schools? *Journal of Toxicology and Environmental Health Part A*, 75, 1371-1380.
- Pérez-Urrestarazu, L., Fernández-Cañero, Franco, A., Egea, G. (2016). Influence of an active living wall on indoor temperature and humidity conditions. *Ecological Engineering*, 90, 120-124.
- Petit, T., Irga, P.J., Torpy, F.R. (2018). Towards practical air phytoremediation: A Review. *Chemosphere*, 208, 960-974.
- Righetto, I. (2018). *Contributo delle piante per la depurazione dell'aria negli ambienti interni. Stato dell'arte e prospettive future*. Thesis in Engineering for Environment and Land, Politecnico di Torino.
- Salthammer, T. (2019). Data on formaldehyde sources, formaldehyde concentrations and air exchanges rates in European housing. *Data in Brief*, 22, 400-435.
- Sanchez, J.A., Ikaga, T., Sanchez, S.V. (2018). Quantitative improvement in workplace performance through biophilic design: A pilot experiment case study. *Energy & Buildings*, 177, 316-328.
- Soreanu, G., Dixon, M., Darlington, A. (2013). Botanical biofiltration of indoor gaseous pollutants - a mini-review. *Chemical Engineering Journal*, 229, 585-594.
- Stigsdotter, U.K. (2015). Nature, Health and Design. *Alam Cipta*, 8(2), 89-96.
- Suzuki, D. (2015). *The impact of green space on heat and air pollution in urban communities: A meta-narrative systematic review*. David Suzuki Foundation.
- Taranzi, E., Parnas, H., Lotan, O., Zaobi, M., Oren, A., Josef, N., Shashar, N. (2019). Nature-Centered Design. How design can support science to explore ways to restore coral reefs. *The Design Journal*, 22:sup1, 1619-1628.
- United Nations Human Settlements Programme. (2011). *UN-HABITAT Annual Report 2010*. Roman Rollnick, Thierry Naudin Editors.
- United Nations Human Settlements Programme. (2016). *The city we need 2.0 towards a new urban paradigm*. UN-HABITAT, Nairobi.
- United Nations Population Division. (2017). *World Population Prospect: The 2017 Revision*.
- United Nations DESA/Population Division. (2018). *World Urbanization Prospects*. Retrived from <https://population.un.org/wup/Country-Profiles/>
- Van der Ryn, S. (2013). Nature-Centred Design. In: *Design for and Emphatic World*, 47-70. Island Press, Washington, DC.
- Wei, X., Lyu, S., Yu, Y., Wang, Z., Liu, H., Pan, D., Chen, J. (2017). Phylloremediation of air pollutants: exploiting the potential of plant leaves and leaf-associated microbes. *Frontiers in Plant Science*, 8.
- Wolverton, B.C., Johnson, A., Bounds, K. (1989). *Interior landscape plants for indoor air pollution abatement*. Final report NASA. National Aeronautics and Space Administration.
- World Health Organisation. 2009. *WHO guidelines for indoor air quality: dampness and mould*.
- World Health Organisation. 2010. *WHO guidelines for indoor air quality: selected pollutants*.
- World Health Organisation. 2016. *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*. WHO Library Cataloguing-in-Publication Data.
- World Health Organisation. 2018. Monograph on the Identification of Carcinogenic Hazards to Humans. List of classification. <https://monographs.iarc.fr/list-of-classifications-volumes/>
- Xue, F., Gou, Z., Siu-Yu Lau, S., Lau, S., Chung, K., Zhang, J. (2019). From biophilic design to biophilic urbanism: Stakeholders' perspectives. *Journal of Cleaner Production*, 211, 1444-1452.
- Yang, D.S., Pennisi, S.V., Son, K., Kays, S.J. (2009). Screening Indoor Plants for Volatile Organic Pollutant Removal Efficiency. *Horticulture Science*, 44, 1377-1381.
- Yangpen, W., Yuming, L., Ding-Chin, C. (2018). Indoor air quality investigation of a university library based on field measurement and questionnaire survey. *International Journal of Low-Carbon Technologies*.



Cumulus Conference
Proceedings Series
06/2019 Bogota

