



# The Human Integration into Sustainable 3D Printing Systems Part II: Design Experimentation

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**Abstract.** This is the second of a two-parts study concerning the integration of the human factors, and in general the integration of all human centred aspects, into fully sustainable and sustainable-oriented 3D printing systems. In particular, this second part of the study will present the design experimentations obtained after the methodological implementation with the Human Centred Design approach on a relevant case study, which is only one of the twenty experimentations carried out. Results obtained in this paper integrate the theoretical and methodological ones developed in the Part I of the study: ‘Methodological Setting and Human-System Integration Strategy’.

**Keywords:** Human Integration · Sustainable 3D printing · Human Centred Design · Design experimentation

## 1 Introduction

Starting from the notions and the research results developed in the theoretical-methodological framework for the Sustainable 3D Printing Systems scenario<sup>1</sup>, the design experimentation described in this second part of the study provides evidences about the feasibility and the potential design implementations achievable by applying the research insights developed until now, beyond the theoretical coherence with the disciplinary domains of Design for Sustainability, 3D Printing and Human Centred Design (HCD).

In particular, the aim of this research phase was to test the effectiveness and the correctness of the design-oriented insights developed in the theoretical framework and, later, to explore potential methodological conflicts for future design implementations. This in order to provide a set of standardized references useful to develop and implement the Sustainable 3D Printing scenario in all possible contexts.

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<sup>1</sup> See the Part I in the paper entitled: ‘*The Human Integration into Sustainable 3D Printing Systems Part I: Methodological Setting and Human-System Integration Strategy*’.

From the cultural point of view – ‘Sustainable Culture’ [1] – this part of the study directly and indirectly refers to the scalability of HCD into sustainable 3D printing scenarios, as well as to the replicability of the research process adopted in this study for other inquiry paths relating Design for Sustainability studies, HCD and productive systems.

## 2 Methodology

As a part of the testing process of this two-parts study, the methodological design experimentation of the strategy for the integration of HCD approach into Sustainable-oriented 3D Printing Scenario has been made on all twenty Sustainable-oriented 3D Printing Systems – as described in the Part 1 – using iterative processes of refinement.

For each HCD open question [2] – Who, What, When, How, Why – a number of ‘Topics for integrating HCD Approach into Sustainable-oriented 3D Printing Systems’ define a holistic strategy – open questions and/or exploratory design actions – useful to integrate the ‘human dimension’ into such sustainable systems.

## 3 Integration of Sustainable-Oriented 3D Printing Systems with the HCD Approach: Design Experimentation and Results

As an illustrative sample of the overall results achieved in this study, the data collected for the Sustainable-oriented 3D Printing System No. 16: ‘Inclusive 3D Printing Systems’ (Table 1) are shown in the following subsections. Data have been therefore organized following the above-described five HCD open questions [2]. This part also provides detailed evidences about the nature and the quality of the insights that can be achieved using the methodology described in the Part I of this study.

**Table 1.** ‘Inclusive 3D printing systems’: Extract from the Sustainable 3D Printing Scenario (See the Part I of the study – footnote No. 2).

Sustainable-oriented 3D Printing Systems	Research Topics and Promising Design Opportunities (not limited to)
16. Inclusive 3D Printing Systems.	<ul style="list-style-type: none"> <li>• Affordable 3D printing systems to prevent child labor</li> <li>• Diversity-inspired 3D printing systems operating on GLocal scenarios/markets (using diversity as a resource)</li> <li>• Socially inclusive 3D printing systems</li> <li>• Community-centered 3D printing systems based on context-based scenario and bottom-up needs</li> <li>• 3D printing systems ‘for All’</li> <li>• Need-based economies supported by 3D printing systems</li> </ul>

### 3.1 Topics for the Integration of HCD: Human Factors

The first set of topics for the integration of HCD concerns the Human Factors domain and in particular it aims to develop important considerations and explorations on the role of humans within the Sustainable 3D Printing scenario. Humans' active and passive relations are studied in order to understand, or strengthen, customers' needs, psychophysical capabilities, wellbeing, satisfaction, wishes and beliefs [3].

Referring to the specific issues concerning the 'human domain' within Inclusive 3D Printing Systems, it is possible to focus the attention on the following topics:

- a) *End-users' role within inclusive systems.*
  - Active involvement of end-users within systems' processes (co-design).
  - Understanding how to generate consistent, empathic and emotional insights (to be converted in human-centred elements for production systems).
- b) *Inclusion-driven human factors.*
  - Improving the affection with inclusive production systems.
  - Mitigating human errors and the cognitive workloads.
  - Understanding how the Social Inclusion can improve the systems' affordance, usability and effectiveness.
  - Understanding how the Social Inclusion can support the development of autopoietic organizational and production factors.
  - Understanding how to improve the affection with inclusive production systems.
- c) *Human's needs and desires.*
  - Exploring the (positive) effects of Social Inclusion on humans' needs.
  - Understanding how to improve human identity in the interactions.
  - Understanding how to boost socio-cultural aspects of inclusive systems.
- d) *Inclusive symbioses between humans and production systems.*
  - Understanding how to improve the awareness on systems' interactions.
  - Understanding how to interpret inclusive patterns and elements to develop consistent symbioses between humans and production systems.
  - Understanding how to generate inclusive meanings to improve human factors and production systems' performance.

### 3.2 Topics for the Integration of HCD: Activities, Tasks and Functions

The second set of topics for the integration of HCD concerns the Functional domain and in particular it aims to develop significant analyses on the solutions' performances within the Sustainable 3D Printing scenario, and their influence on the human sphere. The overall human-system relations are taken into account to explore the quality of users' interactions with products and services including, but not limited to, their effectiveness, efficiency, accessibility and sustainability [3].

Referring to the specific issues concerning the 'functional domain' within Inclusive 3D Printing Systems, it is possible to focus the attention on the following topics:

a) *Inclusion-driven functions, tasks and activities.*

- Exploring compatible activities, tasks and functions (meeting the humans' psychophysical and cognitive-relational capabilities).
- Exploring inclusion-inspired activities, tasks and functions.

b) *Systemic integration.*

- Exploring the integrability of systems' activities, tasks and functions.
- Exploring the co-existence of systems' activities, tasks and functions.
- Exploring the optimization of systems' activities, tasks and functions.
- Exploring the simplification of systems' activities, tasks and functions.

c) *Holistic approach.*

- Exploring goal-oriented activities, tasks and functions using inclusive-oriented analogies.
- Developing humanized activities, tasks and functions in inclusive production systems.

### 3.3 Topics for the Integration of HCD: Interactivities

The third set of topics for the integration of HCD concerns the Relational domain and in particular it aims to develop a holistic framework involving systems' functioning and behavioral patterns within the Sustainable 3D Printing scenario. Discrete and random operational models are studied in order to enrich the human-system interactions, including their usability, affordability and emotional impact [4].

Referring to the specific issues concerning the 'relational domain' within Inclusive 3D Printing Systems, it is possible to focus the attention on the following topics:

a) *Inclusive relations with production systems.*

- Understanding inclusive-oriented relations with production systems, and their parts.
- Understanding inclusive-oriented patterns to support bio-interactions.
- Strengthening and enriching inclusive systems' feedbacks.
- Empowering systems' usability.
- Developing inclusive-inspired interactions using contextual elements.
- Giving consistency to natural relations and bio-interactions.
- Generate meaningful relations and bio-interactions.
- Reducing the psychophysical distance with interactive stimuli.
- Improving the comfort and the pleasantness of interactive stimuli.

b) *Emulations and analogies.*

- Linking humans and ecosystems where the activities will be developed.
- Strengthening inclusive cycles and natural patterns.
- Developing inclusive-oriented languages and bio-centred messages.
- Introducing self-learning mechanisms.

c) *Social Inclusion to support new products and systems' functioning.*

- Understanding systemic bio-relations within inclusive systems.
- Understanding the qualitative factors belonging to inclusive patterns.

### **3.4 Topics for the Integration of HCD: Semiotics and Communications**

The fourth set of topics for the integration of HCD concerns the Socio-Semiological domain and in particular it aims to investigate and make stronger the communicative, cognitive and interpretative elements that enrich the interactions between humans and systems operating in the Sustainable 3D Printing scenario. Sharing activities, as well as explicit and tacit communications are taken into account in order to develop relational patterns that qualitatively and quantitatively improve the human-system interactions [5].

Referring to the specific issues concerning the 'socio-semiological domain' within Inclusive 3D Printing Systems, it is possible to focus the attention on the following topics:

a) *Incorporation of inclusive patterns.*

- Incorporate inclusive key elements (i.e. multisensory) into communicative elements.
- Understanding inclusive patterns for the development of new semiotics.

b) *Inclusive-oriented semantic analogies.*

- Understanding inclusive patterns and phenomena to create consistent messages.
- Developing inclusive stimuli and patterns to support end-users' capability to recognize feedbacks, warnings, affordances, etc.
- Understanding end-users' behaviors to generate clear and fully understandable communications.
- Developing effective inclusive semantics into operating environments.

c) *Inclusion-driven aesthetics.*

- Developing proportions and aesthetic relations using inclusive ideas.
- Understanding inclusive schemes and links among systems' parts (overall aesthetics).
- Understanding how to convert inclusive canons into systems' semiotics.

d) *Use of effective and comprehensive multisensory feedbacks.*

- Understanding the factors related to the pleasantness generable from multisensory feedbacks (strategies for combination).
- Understanding the effects of time on multisensory stimuli.
- Improving the understandability of 'vertical' (monosensory) and 'horizontal' (multisensory) communications.
- Understanding opportunities and limits of multisensory communication.
- Understanding how to improve systems' quality using multidimensional stimuli and multicultural responses.

e) *Inclusive-oriented semiotics.*

- Understanding inclusive-oriented semiotic patterns (conversion into systems' components).
- Understanding how to incorporate inclusive stimuli and inputs into the systems' semiotics.

### 3.5 Topics for the Integration of HCD: Meanings

The fifth set of topics for the integration of HCD concerns the Ideological and Cultural domain and in particular it aims to develop consistent and coherent advances on the philosophical characteristics, and on their integration within the Sustainable 3D Printing scenario. Semantic, functional and cultural characteristics are studied in order to develop meaningful insights connecting humans and system activities [6].

Referring to the specific issues concerning the 'ideological and cultural domain' within Inclusive 3D Printing Systems, it is possible to point our the attention on the following topics:

a) *Inclusive meaningfulness of systems' functions, aesthetics and processes.*

- Developing systems' coherent functions and tasks, which follows end-users' psychophysical and socio-relational capabilities.
- Promoting systems' consistent and inclusive meanings (i.e. avoid solutions' direct and indirect social stigmas).
- Developing inclusive contextual values to systems' functions and tasks.

b) *(Social) Inclusion-inspired systems' awareness and belonging.*

- Generating belonging and empathy on systems using meaning-driven inclusive elements (i.e. using diversity as a multidimensional value).
- Using of Social Inclusion as an interdisciplinary factor to generate socio-technical awareness and belonging.
- Creating consistent inclusion-driven identities and sociotechnical assets.

c) *Normalization of inclusive factors into human activities.*

- Using meaning-driven features to create social empathy and belonging.
- Developing inclusive symbioses and relations within the production systems.
- Developing inclusive patterns that qualitatively improving human activities and habits in the human-systems interaction.

d) *Inclusive branding.*

- Developing inclusive-inspired promotion strategies.
- Developing ecologically compatible and inclusive branding strategies.
- Using inclusive branding strategies to promote systems' bio-qualities.

## 4 Conclusions

This study has been divided into two parts to better explain all research concepts, notions and methodologies used to define a holistic and comprehensive strategy to integrate the so-called ‘human factor’ into Sustainable 3D Printing Systems, as well as the design results. This has been done using a cross-fertilization process combining both design-oriented insights belonging to Design for Sustainability studies and HCD. Whilst the first part explores the theoretical and methodological relations of disciplines within the new Sustainable 3D Printing scenario, this second part has shown evidences about the results achievable through the use of HCD approach.

In particular, even in some very complex systems like the ones belonging to the new multidimensional framework of Social Inclusion applied to 3D printing, there is a remarkable quali-quantitative improvement of the human-centred qualities of productive systems.

By using the HCD approach, this study has proved that it is possible to generate significant interlinks between sustainable-oriented production systems and the HCD discipline. As described by the ‘Research Topics for integrating HCD Approach into Sustainable-oriented 3D Printing Systems’ (see extracts contained in Table 1 of Part I and in Table 1 of Part II), there is a clear relation between this study and the principles of Human System Integration.

In conclusion, this two-parts study is relevant because it organizes relevant advances of Design for Sustainability, 3D Printing and HCD domains, and proposes a multidisciplinary experimental convergence by integrating human dimensions, sustainable-oriented cultures and modern production systems. This is perfectly in line with the ‘Sustainable Culture’ characterizing the Design discipline and the ones revolving around the improvement of production systems, like the ones involving 3D printing.

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