Design for Social Sustainability in Digital Fabrication for Development in the Global South

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This dissertation is submitted for the degree of

Doctor of Philosophy

Gonville and Caius College February 2020

To everyone on the other side of the invisible line.

Declaration

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text. It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. It does not exceed the prescribed word limit set by the Engineering Degree Committee.

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Abstract

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Context: The demand for humanitarian and development aid has risen to an unprecedented level. With an urgent need for new solutions, the aid sector has started turning to digital fabrication (3D printing, laser cutting and computer numerical control (CNC) milling). Collectively, these initiatives are referred to as Digital Fabrication for Development (DF4D). It is commonly believed that DF4D can support more low-cost, appropriate and localised forms of production in the Global South.

Problem: Despite rhetoric about the transformative potential of DF4D, there is concern that technology projects in the aid sector have historically failed to create lasting impact. It is put forward that social sustainability is currently lacking and that this is limiting the success of DF4D. Despite recognition that social sustainability is the foundation for sustainable development, it is a challenging concept that is often neglected in mainstream sustainability research. In addition, the role of design in promoting social sustainability has not been well understood. Until this problem is addressed, it is believed that DF4D will not succeed in creating the social impact it desires.

Research aim: To investigate how design can promote social sustainability in DF4D.

Methodology: This thesis follows a pragmatic research paradigm. First, an exploratory study is conducted with fourteen case studies to validate that social sustainability is currently lacking in DF4D. Building on these findings, the main study is conducted with three case studies: a 3D printed otoscope in Nepal; a digitally fabricated prosthesis in India; and, a digital fabricated suction pump machine in Kenya. The main study diverges in two directions, with the first part focusing on an analytical approach and the second part taking a critical systems approach. In the analytical approach, thematic coding of case study data is used to identify the key principles of Design for Social Sustainability in DF4D. In the critical systems approach, Actor-Network Theory is used to investigate the networks of DF4D projects.

Results: The analytical approach results in a normative framework to support Design for Social Sustainability in DF4D. It offers practical guidelines that are relevant in project planning and evaluation. The framework highlights the need for radical, systems-focused solutions. It reveals that design can trigger social sustainability at product, process and paradigm levels. The critical systems approach explores an interpretative version of Design for Social Sustainability. It supports the development of an initial toolkit that allows actors to collaboratively map their own networks during ongoing projects. Network analysis of the case studies clarifies the linkage between participation and Design for Social Sustainability. Reciprocity is highlighted as a key network metric that reveals (in)equitable relationships. The results of the analytical and critical systems approaches are compared to identify their complementary insights. It is put forward that Design for Social Sustainability in DF4D demands several shifts in practice from: products to capabilities; exogeneous to endogenous development; passive to active actors; quick fixes to open-ended solutions; and, one-off projects to scalable interventions. It is argued that Design for Social Sustainability also has the potential to shape sustainability transitions beyond the project-level.

Theoretical implications: Synthesis of fragmented knowledge on Design for Social Sustainability and identification of its key principles in the DF4D context.

Practical implications: The development of a practical framework and an initial toolkit that can support practitioners in DF4D to develop more socially sustainable solutions.

Methodological implications: Explanation of how and why analytical and critical systems approaches can provide complementary insights for exploring complex phenomena.

Dissemination

Corsini, L., Aranda-Jan, C. B., & Moultrie, J. (2020) The impact of 3D printing on the humanitarian supply chain. *Production Planning & Control*. (Forthcoming)

Corsini, L. & Moultrie, J. (2020) Using systems thinking to investigate the sustainability of digital fabrication projects in the humanitarian and development sector. *International Journal of Business and Systems Research*. (Forthcoming)

Corsini, L. & Moultrie, J. (2020). Humanitarian makerspaces in crisis-affected communities. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*. 1-13.

Corsini, L. & Moultrie, J. (2019) Design for social sustainability: using digital fabrication in the humanitarian and development sector. *Sustainability*. 11(13), 3562.

Corsini, L., Aranda-Jan, C. B., & Moultrie, J. (2019). Using digital fabrication tools to provide humanitarian and development aid in low-resource settings. *Technology in Society*. 58, 101117.

Corsini, L. & Moultrie, J. (2019) Using systems thinking to investigate the sustainability of digital fabrication projects in the humanitarian and development sector. In *Proceedings of 4D Conference 2019*, Osaka, Japan.

Corsini, L., Aranda-Jan, C. B., Henderson, C. & Moultrie, J. (2019). Participatory design in low resource settings: a case study of Simprints. In *Proceedings of the Academy of Design Innovation Management Conference 2019*, London, UK.

Corsini, L., & Moultrie, J. (2018). The role of makerspaces for crisis-affected communities: benefits and challenges. In *Proceedings from the Fab14 + Fabricating Resilience Research Papers Stream*, Toulouse, France.

Corsini, L., & Moultrie, J. (2018). A review of making in the context of digital fabrication tools. In *DS92: Proceedings of the DESIGN 2018 15th International Design Conference*, Dubrovnik, Croatia.

Corsini, L., & Moultrie, J. (2017). An exploratory study into the impact of new digital design and manufacturing tools on the design process. In *DS 87-2 Proceedings of the 21st International Conference on Engineering Design (ICED 17) Vol 2: Design Processes, Design Organisation and Management*, Vancouver, Canada.

Acknowledgements

First and foremost, this research could not have been possible without the people who generously contributed to this work. In no particular order I would like to thank Field Ready, the Biomedical Engineering and Technology Innovation Centre at the Indian Institute of Technology-Bombay, Ratna Nidhi Charitable Trust (RNCT) Mumbai, Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS) Jaipur, FabLab Nairobi, MakerSpace Nairobi and Kenyatta National Hospital. I am grateful to all the people I met at RNCT and BMVSS for their openness and particularly insightful reflections. I would also like to thank Anitha Srinivas, who provided guidance and translation in India. Our long car journeys together made this research much richer.

I would also like to acknowledge the funding that I received from the EPSRC, Department of Engineering, School of Technology, and Gonville and Caius College to complete my PhD and field work. This research was supported by the EPSRC Doctoral Training Programme, grant number EP/L504920/1.

A huge thanks to my supervisor James Moultrie for his support and guidance over the years, and to my advisor Tim Minshall for his constant encouragement. Thanks also to Clara Aranda-Jan for her continuing friendship and guidance, and to Lara Allen for her sage advice. The Institute for Manufacturing has been a wonderful, welcoming place to work on my PhD and I am indebted to the PhD students, postdocs and other staff that make up this community, especially to the members of the Design Management Group past and present.

Finally, thank you to my friends who rooted and continue to root for me - Tamsin, Aoife, Emma, Giselle, Philippa, Laura, Coralie, Courtney S, Laura ML, Abby, Courtney F, Gabby and Cassi. Also to Byrnie, Pam, Iris, Mary Ann, Julie, Ezra and Aimee who made home a home. My deepest thanks is to my family who taught me the two most important life lessons of love and hard work. My parents, Alberto and Janina who are unfaltering. To Francesco, Nicola, Maria, Rita, Eugenia, Mario, Gino, Ida, Ula and Halim who all inspired me in different ways. And to Moh, who I could never thank enough. He is my anchor and my second pair of eyes.

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Chapter 1 Introduction

1.1 Introduction to the chapter

The demand for humanitarian and development aid has risen to an unprecedented level (Anheier et al., 2018; Behl & Dutta, 2018). Global rises in conflict, displacement, disasters, epidemics, inequality, and neglect are all placing increasing pressure on the aid sector (Development Iniatives, 2018b). With an urgent need for new solutions, the aid sector has started turning to digital fabrication (3D printing, laser cutting and computer numerical control (CNC) milling). Collectively, these initiatives are referred to as Digital Fabrication for Development (DF4D). Despite the potential of DF4D, there is concern that many technology projects in the aid sector have failed to create lasting impact (Dunmade, 2002; Pattnaik & Dhal, 2015). In this research, it is put forward that social sustainability is a key gap and until this is resolved, DF4D will fail to deliver the impact it desires. This thesis focuses on the role of design in bringing about social sustainability. It contributes to the conceptual and practical development of Design for Social Sustainability, in the context of DF4D.

To begin with, Section 1.2 explains the motivations for using digital fabrication in the aid sector and summarises what is currently known about DF4D. Section 1.3 raises concern about the historical applications of technology in the aid sector. It draws on research from the related field of Information and Communications Technologies for Development to suggest that DF4D may also fall short of its goals. Section 1.4 suggests that social sustainability is a key gap. Section 1.5 introduces the idea that design is a catalyst for social sustainability, and proposes that Design for Social Sustainability is a missing piece of the puzzle. Section 1.6 sets out the main aims and key question of the thesis. Finally, Section 1.7 provides an outline of this thesis and its contributions.

1.2 How can digital fabrication help to solve humanitarian and development problems?

> *"The story of the [Global South] and technology if it is told at all is one of transfer, resistance, incompetence, lack of maintenance, and enforced dependence on rich-world technology. Imperialism, colonialism, and dependence were the key concepts, and the transfer of technology from rich to poor, the main process." (Edgerton, 2007)*

Typically when a crisis strikes, products are imported from factories or warehouses in the Global North to their context of use in the Global South (Van Wassenhove, 2006). Most products in the aid sector are designed and manufactured far away from their end users (Sandvik, 2017; Wood & Mattson, 2016). In recent years, this model has been largely criticised for failing to provide adequate solutions to global challenges (Tatham et al., 2015). Imported products are often not suitable for the local context (Aranda et al., 2016), they are difficult and expensive to transport (Falasca & Zobel, 2011; Kovács & Spens, 2009) and they disincentivise the development of local knowledge and manufacturing (H. A. Er, 1997; James, 2017).

Recognising that existing solutions are insufficient, digital fabrication is emerging as the basis for an alternative model. Digital fabrication refers to a set of manufacturing processes that enable the creation of physical objects from digital models created in Computer Aided Design (CAD) software (Gershenfeld, 2012). Although what exactly classifies as a digital fabrication tool has been much debated, this study focuses on three widely recognised and popular tools: 3D printing, laser cutting and computer numerical control (CNC) milling (Gershenfeld et al., 2017). Although some of these technologies have existed since 1950s, they were previously only accessible by industry. In the last decade, these tools have started migrating 'from the factory to the desktop' and are now more widely available to the mass market (Mota, 2011; Ratto & Ree, 2012). Broadly speaking, *desktop digital fabrication* is smaller in physical size, and is less expensive and complex than industrial technologies. Despite the popularity of this term, a precise definition does not exist in the literature. This thesis considers desktop digital fabrication to refer to the tools that are commonly found in community-based fabrication workshops (i.e. makerspaces, FabLabs, TechShops and hackerspaces). From now on, digital fabrication will be used to refer to desktop digital fabrication.

Much has been written about digital fabrication's ability to produce low-cost and customised items (I. Gibson et al., 2015; Saripalle et al., 2016). However, it is the potential for digital fabrication to enable local and distributed manufacturing that could radically change the provision of items in the aid sector (Birtchnell & Hoyle, 2014; Corsini et al., 2020). Specifically, local manufacturing could help to bypass lengthy supply chains (Tatham et al., 2015, 2018) and increase local resilience and self-sufficiency (Birtchnell & Hoyle, 2014; Freeman et al., 2017; Loy et al., 2016). Additionally, it could add value to local economies, therefore reducing dependency on imported goods and foreign aid (Corsini & Moultrie, 2018; Fox, 2016; James, 2017).

In the grey literature, DF4D projects are receiving widespread acclaim (S. Jones, 2015; Ramalingam et al., 2016; Strickland, 2017; B. Young, 2017). However, existing research on DF4D is very sparse and academia is failing to keep pace with progress (Seo-Zindy & Heeks, 2017). An initial review by Corsini, Aranda-Jan, & Moultrie (2019) showed that digital fabrication is being used to produce a range of items including prosthetics, medical tools, emergency shelters, spare parts and communications infrastructure (see Table 1.1). However it discovered a lack of critical analysis in the field: articles often repeated well-known benefits of digital fabrication without providing evidence; the majority of articles were descriptive case studies written by project implementers; articles tended to focus on positive aspects only; and, there was little attention given to the specific use-context, making it difficult to assess the reality of DF4D. Whilst the potential of DF4D seems promising, it is clear that academic research is lagging behind progress in the sector. There is an urgent need for critical and contextual research that goes beyond reporting about one-off interventions.

Table 1.1 – Projects by sector, application and manufacturing technology (from Corsini, Aranda-Jan and Moultrie, 2019)

Sector	***Applications***	***Reference***	***3D printing***	***CNC milling***	***Laser cutting***	***Non-digital fab.***
Architecture	Shelters and assemblies	Botha & Sass (2006)		X		
		Carlow & Crolla (2013)		X		
		Griffith et al. (2012)		X		X
		Peinovich & Fernández (2012)		X		X
		Yeung & Harkins (2010)			X	
Medical	Medical tools and supplies	Baden et al. (2015)	X			
		Belliveau (2016)	X			
		Hafez et al. (2015)	X			
		Ibrahim et al. (2015)	X			
		Ishengoma & Mtaho (2014)	X			
		D. L. King et al. (2014)	X			
		Pavlosky et al. (2018)	X			
		Rismani & Van Der Loos (2015)	X			
		Rogge et al. (2017)	X			
		Saripalle et al. (2016)	X			
		Wijnen et al., (2014)	X			
		Wong, (2016)	X			
		Zhang et al. (2013)	X			
	Prosthetics	Arabian et al. (2016)	X			
		Belliveau (2016)	X			
		Dally et al. (2015)	X			
		Ibrahim et al. (2015)	X			
		M. King et al. (2015)	X			X
		Maric et al. (2016)	X			
		Nisal et al. (2017)	X	X		
		Pearce et al. (2010)	X			
		Phillips et al. (2015)	X			X
		Rismani & Van Der Loos (2015)	X			
		Valencia et al. (2017)	X	X		
		Zuniga et al. (2015)	X			
Spare parts		De la Torre et al. (2016)	X			
		Ishengoma & Mtaho (2014)	X			
		James (2017)	X			
		Pearce et al. (2010)	X			
		Saripalle et al. (2016)	X			
		Schoning & Heidemann (2016)	X			
Utilities	Communications tower	Stevens et al. (2014)	X			X
	Cook stoves	James (2017)	X			X
		Mok (2015)	X			X
	Rural electrification	Bassett et al. (2015)	X			
		D. L. King et al. (2014)	X			
		Pearce et al. (2010)	X			
Water and sanitation	Rainwater catchment	Hafez et al. (2015)	X			
		Ibrahim et al. (2015)	X			
	Water pipe fittings and connectors	Belliveau (2016)	X			
		James (2017)	X			X
		Loy et al. (2016)	X			
		Tatham et al. (2015)	X			
Others	Disaster relief robot	Chu et al. (2015)	X			
		Lacaze et al. (2014)	X			
	Germinator	D. L. King et al. (2014)	X			

1.3 How can DF4D avoid the pitfalls of previous technology projects in the humanitarian and development sector?

Set against a wave of optimism about the potential of DF4D is the reality that many technology projects in the humanitarian and development sector have not worked (Archibugi & Pietrobelli, 2003; Pattnaik & Dhal, 2015). Although it is a common belief that technology will accelerate wealth production and reduce poverty (Nichols, 2007; Salam & Kidwai, 1991), there is a graveyard of failed technology projects in the aid sector (Borland, 2014; Dodson et al., 2012; Heeks, 2002; Loy et al., 2016). Technology has been criticised for 'shifting the burden' (Archibugi & Pietrobelli, 2003), failing to address underlying social problems (Pattnaik & Dhal, 2015; Rose, 2016), and distorting interests in the aid sector (Scott-Smith, 2016).

Previous research on DF4D is limited and the mainstream narrative has been largely positive (Corsini, Aranda-Jan, & Moultrie, 2019). However, a historical review of the related Information and Communications Technology for Development (ICT4D) movement raises some concerns about DF4D. Since the 1990s, the proliferation of Information and Communications Technologies (ICTs) in the Global South has been widely hailed as a driver of growth and productivity (European Parliament, 2015). The concept of 'technology leapfrogging' has been frequently used to describe the penetration of mobile phones and solar technology in the South (Fong, 2005). Underlying this view of ICTs is the so-called Enlightenment epistemic that progress is marked by increasing technological development (Cherlet, 2014).

More recently, people have started to draw parallels between ICT4D and DF4D to suggest that digital fabrication could also enable innovation in regions without industrial manufacturing infrastructure (Birtchnell & Hoyle, 2014; Fox, 2014; Heeks, 2017). 3D printing has also been hailed as a leapfrog technology Some authors even consider digital fabrication to be a building block of ICT4D: "*it is safe to state that 3D printing and, more generally, digital fabrication constitute powerful and innovative tools for ICT4D*" (Stickel et al., 2015).

Although mainstream accounts present ICT4D as a force for social good, critical perspectives have also examined the 'dark side' of ICT4D (Poveda & Roberts, 2018; Unwin, 2017; Walsham, 2017). Notably its effects on poverty reduction have been contested (Adera et al., 2014; European Parliament, 2015) and many authors have pointed out the high failure rates of projects (Harris, 2016; Lin et al., 2015, p. 4; Toyama, 2010, 2011). Critical accounts argue that ICT4D tends towards technology determinism (Cherlet, 2014) and is a new form of digital imperialism (Jimenez & Roberts, 2019). For example, Nussbaum (2010) specifically critiques the One Laptop Per Child initiative, which aims to improve access to education, for imposing an overly 'Western mindset' on 'African problems'.

Among these studies, sustainability has been identified as a problem in ICT4D (Ali & Bailur, 2007; Heeks, 2010; Marais, 2011; Marais, 2015). Consequently, this raises the question, how can DF4D avoid the same pitfalls of ICT4D and how might discourses on sustainability provide a useful starting point?

1.4 Is social sustainability a missing piece?

Although the concept of sustainability has existed for centuries, the word itself has a relatively recent history. Since the shift from hunter-gatherer to agricultural communities around 12,000 years ago, the preservation of future resources has always been a concern[1]. However it was not until 1713 that the German word, *Nachhaltigekeit* meaning "sustained yield" was first used in a forestry handbook to refer to the practice of harvesting a forest without undermining its ability to regenerate. Sustainability, originating from the Latin words *sus* meaning 'up' and *tenere* meaning 'to hold', became popular in the 1970s as awareness of environmental issues increased (Kidd, 1992).

Since then, the conceptual development of sustainability has expanded and sustainability is widely regarded as consisting of social, economic and environmental dimensions (Elkington, 1999; Scott Cato, 2012). More commonly, it is related to the definition of sustainable development found in the Brundtland report: "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987). It has been argued that sustainability should be the goal of humanity, whereas sustainable development is the means by which sustainability might be achieved (Shaker, 2015).

[1] During the First Agricultural Revolution Homo Sapiens stopped relying on hunting and gathering and instead started cultivating crops and domesticating animals (Harari, 2015).

Within the aid sector, sustainability is often used to refer to a project or an organisation's ability to sustain itself: "*measuring whether an activity or impact is likely to continue after donor funding has been withdrawn*" (ALNAP, 2007 in Haavisto & Kovács, 2014) or "*being able to survive so that it can continue to service its constituency*" (Weerawardena et al., 2010 p.247). However these definitions seem to be closer to the meaning of *sustained* than sustainability[2]. It could also be said that these definitions are underpinned by economic concerns and thus represent 'weak' sustainability. 'Weak' sustainability assumes that man-made capital is substitutable with other types of capital, whereas 'strong' sustainability is rooted in the belief that different forms of capital are complementary but not substitutable, and thus must be maintained separately over time (Costanza & Daly, 1992).

Several authors have criticised sustainability studies for fetishizing economic growth (Dodds, 1997; T. Jackson, 2013). Elsewhere authors have called for sustainability to be recognised as more than just the 'green agenda' so that social practices can be considered as part of a holistic approach (Missimer et al., 2017a; Zink, 2014). Whilst there is growing recognition of the importance of social sustainability, it is often ignored in multi-pillar approaches to sustainability (Griessler & Littig, 2005). Many interdisciplinary models position environmental or economic factors as their main concerns, leading to a scarcity of research that examines how to sustain and promote social systems (McKenzie, 2004; Missimer et al., 2017a). Social sustainability itself is a nebulous concept and a plurality of definitions exist (Vallance et al., 2011; Weingaertner & Moberg, 2014). Broadly speaking, social sustainability is concerned with the preservation of the social system in which people are not subject to structural obstacles to health, influence, competence, impartiality, and meaning-making (Missimer et al., 2017b). In other words, social sustainability is concerned with the wellbeing and flourishing of our societies now and in the future[3].

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[2] According to the Oxford English Dictionary, sustained is "*kept in existence; existing or real*".

[3] A broad understanding of flourishing and wellbeing is intended here to include physical, psychosocial and emotional dimensions. Several authors have used these combinations of terms in the past. For example, O'Neill (1996) argues that the common good rests upon human wellbeing and flourishing. Ehrenfeld (2008) identifies human flourishing as the ultimate goal of sustainability. VanderWeele (2017) explains that human wellbeing is akin to flourishing: *"flourishing itself might be understood as a state in which all aspects of a person's life are good. We might also refer to such a state as complete human well-being, which is again arguably a broader concept than psychological well-being."*

The protection of communities' wellbeing is an overarching goal of the aid sector (Eyben, 1995). Reflecting on the failure of integrated sustainability approaches to address social issues, it was hypothesised that social sustainability could be a significant gap in DF4D. Within the literature on ICT4D, social sustainability is recognised as a key driver of project success, even if social sustainability itself seems to be poorly defined or conceptually inconsistent (Ali & Bailur, 2007; Marais, 2011; Marais, 2015; Masiero, 2011). Returning to the earlier question of how DF4D might avoid the same pitfalls of ICT4D, the researcher began to wonder whether social sustainability could offer a way forward. It was therefore decided to begin investigating social sustainability as a way of addressing concerns about DF4D.

1.5 Could design be a catalyst for social sustainability?

> *"Change only occurs in two ways: by accident or by prefigured intent (which is de facto design)."* (Fry, 2011 p. viii)

It has been said that design as a word has lost its meaning. It has become a 'suitcase word' that means so many different things that almost anything can be called design (Ito, 2016). The first Conference on Design Methods in 1962, is often referred to as the beginning of design as a subject of enquiry (Cross, 1993; J. C. Jones & Thornley, 1963). Since then, design focus has shifted from the creation of physical to immaterial things, from products to services and systems, and from a discipline practiced solely by expert designers to one that involves the participation of the collective (Ceschin & Gaziulusoy, 2019; Manzini, 2015b).

What is consistent then about design throughout its evolving identities, is its ability to catalyse change. Design itself is a deliberate act of moving from the current status quo, to another preferred state (Fuad-Luke, 2009). A look at the Italian word for design, *progettare* reveals a much richer meaning that signifies to plan, to imagine, to envision. Within the word is rooted design's ability to see beyond what does not yet exist (Pacenti, 2019). Design is thus a means by which new realities might come into being. If social sustainability is one such a reality, then design is clearly a powerful actor in its attainment. This thesis thus elaborates on the earlier suggestion that social sustainability is a key gap in DF4D, to put forward that Design for Social Sustainability (DfSS) is a missing piece in the puzzle.

1.6 Research aims, question and scope

This thesis is motivated by the realisation that many technology projects in the aid sector have failed. In an effort to avoid the same fate for DF4D, this thesis seeks to explore how design can promote social sustainability in DF4D initiatives. It aims to contribute to the conceptual and practical development of DfSS in the DF4D context.

The thesis is driven by the following central research question:

- How can design promote social sustainability in DF4D?

This study explicitly focuses on DF4D in the Global South, which refers to low and middle income countries in Asia, Africa, Latin America and the Caribbean (Hollington et al., 2015). Within this thesis, the aid sector is used to refer to both the humanitarian and development sectors. In theory, humanitarian aid is a short-term response to crises that quickly aims to save lives and alleviate suffering (Development Iniatives, 2018a). In contrast, development aid deals with chronic problems such as poverty and social inequality (OECD, 2020). It focuses on long-term programmes to promote social and economic development. In reality, the distinction between humanitarian and development aid is not clear cut. There are an increasing number of complex, protracted crises in which short-term interventions and quick exit strategies do not exist[4]. In the last decade the boundary between humanitarian and development aid has become more blurred and many comparable projects fall under the remit of both sectors (Buchanan-Smith & Fabbri, 2005). For this reason, this thesis considers DF4D to include initiatives in both the humanitarian and development sector.

1.7 Thesis outline

The thesis is structured in three major parts. The first part focuses on building up an understanding of the research problem and establishing a theoretical foundation for the thesis.

[4] Protracted crises, which extend for many years, have been called the "new normal" in humanitarian crises. In Somalia, the West Bank and Gaza Strip, humanitarian crises have existed for decades (Sova, 2017).

Chapter 1 introduces the research by summarising the research context, the key aims and underlying question of the thesis. It reflects on the historic failure of technology projects in the aid sector to put forward that social sustainability might be a gap in DF4D. It is suggested that until social sustainability is addressed, DF4D will not succeed in creating the positive social impact it desires. Recognising the potential for design to catalyse change, it is suggested that DfSS is a missing piece of the puzzle in DF4D.

Chapter 2 describes the research methodology and research design that guides this thesis. The researcher's own experience and beliefs are set out to help guide the reader. Pragmatism is selected as the underlying philosophical position, and it is put forward that there are different ways of looking at the same problem. The chapter explains that the research begins by conducting multiple case studies as part of an exploratory study. This is followed by the main study, which gathers data from a smaller number of case studies in the healthcare sector.

Chapter 3 conducts an exploratory study to validate whether social sustainability is missing in DF4D. Given the lack of existing research on DF4D, empirical data is collected from multiple case studies. The chapter finds that contrary to popular rhetoric about DF4D, the majority of projects are total or partial failures. It is observed that social sustainability is currently lacking in DF4D and that there are inadequate solutions to address this problem. This chapter provides important evidence of the need for this research to better understand DfSS in DF4D.

Chapter 4 turns to the literature to focus on the role of design in promoting social sustainability. It explains that although design is widely recognised as an important change agent, it has been largely neglected in mainstream research on social sustainability. The chapter presents a systematic literature review to build up a conceptual understanding of DfSS. It identifies some initial key themes of DfSS and establishes an important theoretical foundation for this work. It points out the need for a contextually appropriate understanding of DfSS to advance DF4D.

The second part of the thesis presents the main study. This part of research diverges to take two different approaches in order to conceptually and practically develop DfSS in DF4D. Data is collected from three case studies in the healthcare sector.

Chapter 5 takes an analytical approach to explore DfSS in DF4D. It builds on previous work to develop a normative framework that identifies the key principles of DfSS. The case studies are evaluated to demonstrate the value of the framework. It is suggested that the framework can offer guidance for practitioners during the planning and evaluation stages of projects.

Chapter 6 takes a critical systems approach to investigate DfSS in DF4D. Actor-Network Theory is selected as a methodological guide to explore the networks of DF4D projects. The chapter presents Designet, an initial participatory toolkit that allows actors to map the networks of their own projects. Designet is used to map the networks of the main case studies, which are then analysed in this chapter. It is put forward that network-mapping can help to better align DF4D projects with DfSS.

The final part of the thesis reflects on the main implications of this research. It discusses the findings and draws on additional theory to build up a richer picture of DfSS in DF4D.

Chapter 7 discusses the findings by comparing the analytical and critical systems approaches. It proposes that their practical outcomes provide better coverage than any single perspective. Their complementary insights are discussed at length. The chapter also considers the broader implications of the findings, reflecting on how design can promote social sustainability in aid sector, beyond the DF4D project-level.

Chapter 8 concludes the thesis by summarising the main findings, discussing the limitations and suggesting areas for future research. It notes that prior to this study, knowledge on design's role in promoting social sustainability was highly fragmented. This thesis synthesises existing knowledge on DfSS and further identifies its relevant principles, specifically for DF4D. It also addresses the need for a practical way to DfSS in DF4D. Moreover, this research clarifies the value of exploring complex societal problems from different points of view, specifically by combining an analytical and critical systems approach.

1.8 Summary

This chapter started by introducing the increasing demand for humanitarian and development aid across the world. It explained that digital fabrication is emerging as a potential new solution to these unmet needs, by supporting more appropriate and locally driven initiatives. Despite growing interest in DF4D there is a paucity of academic research in the field. Among the few studies that exist, most articles tend to focus on positive reports of DF4D. However, historical applications of technology in the aid sector have been widely criticised. A look at the related field of ICT4D reveals that many projects have failed. Reflecting on how DF4D might avoid the pitfalls of previous technology initiatives, it was suggested that further work is needed to better understand social sustainability. It was also put forward that design could help to promote social sustainability, as it envisions and gives form to new realities. This led to the suggestion that Design for Social Sustainability is a missing piece of the puzzle in DF4D. This chapter has introduced the research context and set out the central research question: how can design promote social sustainability in DF4D? It has also presented an outline of the thesis to help guide the reader. The next chapter follows on from this introduction to explain the overall research methodology and design.

List of Abbreviations

3DP – 3D printing
ANT – Actor-Network Theory
CAD – Computer Aided Design
CNC – Computer Numerical Control
DF4D – Digital Fabrication for Development
DfSS – Design for Social Sustainability
ICT – Information and Communications Technology
ICT4D – Information and Communications Technology for Development
MLP – Multi-Level Perspective

Chapter 2 Methodology

2.1 Introduction

The previous chapter set out the research context and identified the main aims and scope of the thesis. Specifically it highlighted the growing urgency for humanitarian and development solutions, against which interest in DF4D is now flourishing. Despite the potential of DF4D, the chapter pointed out that many technology projects in the aid sector have historically failed and neglected the role of social sustainability. It was put forward that design could play an important role in bringing about social sustainability in DF4D, however its potential to do so is poorly understood at present. This chapter seeks to clarify the research methodology and design that guides the exploration of DfSS in DF4D. Section 2.2 presents the research onion, a framework that is used to structure the research methodology. Section 2.3 introduces pragmatism as the philosophical position. Section 2.4 describes why an abductive approach was taken, Section 2.5 justifies the use of case study research and Section 2.6 explains why mixed methods research was chosen. Then, Section 2.7 provides an overview of the data collection and analysis methods. It also tackles ethical issues and concerns about quality. Finally, Section 2.8 introduces the researcher, positioning the inquirer as inseparable from the research phenomenon.

2.2 The research onion

According to Saunders et al. (2009) research is a multi-layered process that can be represented as an onion. Each layer indicates a decision that the researcher must make about the research philosophy, approach, strategies, choices, time horizons and, techniques and procedures (see Figure 2.1). In this chapter, an adapted version of the research onion is used as a guide to introduce the research methodology and research design that guides this thesis.

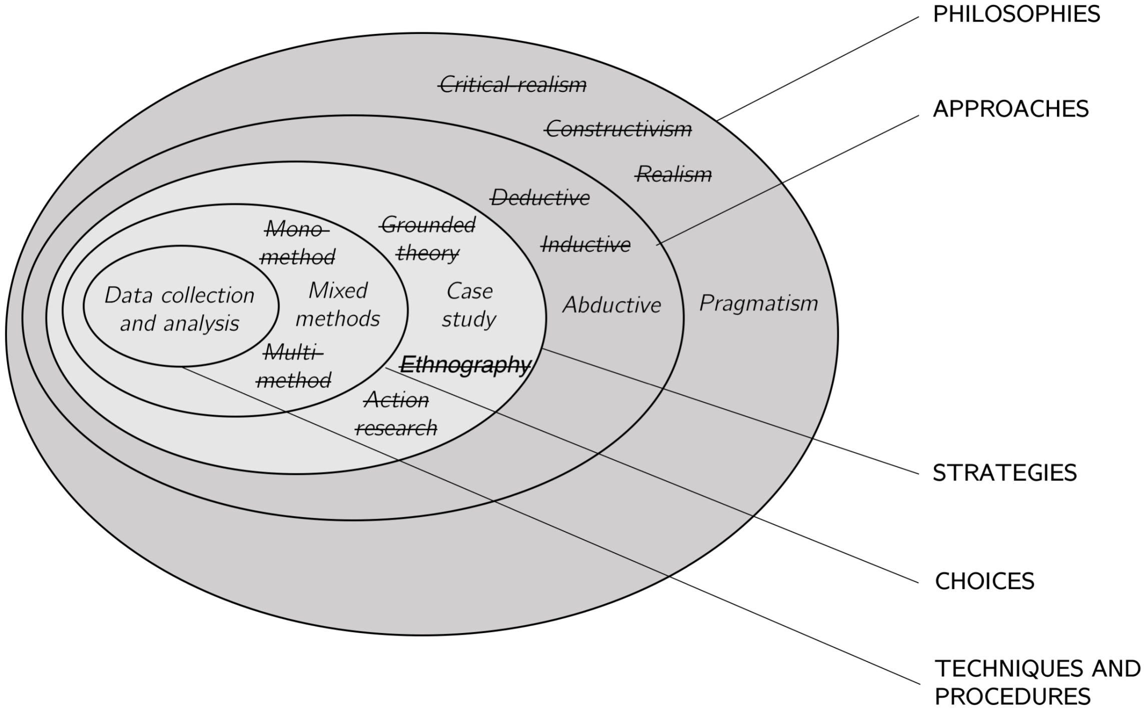

Figure 2.1 Research onion adapted from Saunders et al. (2009)

Traditional philosophies of knowledge are described as metaphysical because of their focus on ontology (the nature of existence) and epistemology (the nature of knowledge) (Hacking, 1983). This dominant way of thinking has led to a dualism between realism (or post-realism) and constructivism. Realism contends that a single reality exists irrespective of our perceptions and that evidence can be used to explain this reality. Knowledge is subject to error and so theories can be revised subject to new evidence. On the other hand, constructivism denies the existence of an independent reality. Instead multiple realities are constructed depending on different people's beliefs and everyone has their own version of the 'truth' (Morgan, 2014a p.38).

In recent years, pragmatism has been put forward as an alternative to these metaphysical paradigms (Creswell & Creswell, 2018). The work of pragmatist philosophers such as Charles Sanders Pierce, John Dewey and George Herbert Mead are receiving renewed attention. Specifically, pragmatism sets aside discussions on ontological and epistemological paradigms, instead taking the view that all knowledge of the world is based on experience. It shifts the focus of study away from debates about 'truth' back to the study of methods, by asking researchers about how they make the choices they do and the relative impact of making such choices (Morgan, 2014b). In this sense, pragmatism is more concerned with 'what works' and selecting the most suitable approach in any particular context (Saunders et al., 2009).

For this reason, researchers often cite pragmatism as a way to justify greater flexibility in research methods. This study, however, underlines the important philosophical underpinnings of pragmatism that are particularly relevant to this work. In Morgan's (2014b) analysis of pragmatism, he draws heavily on the pragmatist philosophy of Dewey. He explains that Dewey highlighted the importance of human experience over abstract concerns. In this model of enquiry, experiences create meaning through the interaction of belief and action. They cannot be separated from their historical and cultural context, as they are naturally linked to belief and action. In other words, the researcher and the subject cannot be separated, just as knowing cannot be separated from doing. This is in stark contrast to the idea that researchers should remain objective and not get too involved with their subjects (Welman et al., 2005 p. 199).

Pragmatism was also selected for this study because of its compatibility with design and social research. Within the design discipline, experience is well-recognised as source of knowledge creation. Donald Schön's (1983) conceptualisation of the reflective practitioner and Nigel Cross' (2001) Designerly Ways of Knowing both describe how the designer learns by engaging with their physical environments. Within social research, pragmatism has been recognised as a key lever for emancipatory research. For example, Denzin (2010) argues that pragmatism *"will always be a moral, political and value-laden enterprise"* because of its inherent contextual and emotional focus. Feminist theories have also highlighted its potential to privilege the struggles of marginalised groups (Seigfried, 1996). Finally, pragmatism has also found its place postcolonial and decolonial studies. Santos (2016) introduces the concept of epistemicide, the murder of knowledge in the Global South. He calls for the recognition of alternative forms of knowledge to the Enlightenment thinking which dominates in the Global North. Pragmatism directly responds to this by providing a means to embrace a *"plurality of worlds and beings"* (Escobar, 2018).

2.3 An abductive approach

Abduction is a complementary approach to pragmatism. Whereas deduction uses observations to test theory and induction builds up theory from observations, an abductive approach consists of going 'back and forth' between empirical and theoretical evidence to create new knowledge

(Creswell & Creswell, 2018; Dubois & Gadde, 2002). It is grounded in the belief that theory cannot be created without empirical observation and visa-versa. However, it is more than just combining deductive and inductive approaches (Saunders et al., 2009) and requires the systematic matching of theory and reality (Dubois & Gadde, 2002).

In the previous chapter it was explained than existing theory on DF4D is very sparse. It was therefore decided to gather empirical data on DF4D projects. At the same time, literature on social sustainability was reviewed in order to build up an understanding of this construct. The literature was constantly referred to in order to make sense of the observations and to guide the data collection as part of an iterative process (G. Thomas, 2010). Subsequently, a literature review on DfSS was conducted to help build a theoretical foundation for the research. A process of matching this theory with the empirical data collected in the main study helped to create new knowledge. Additional theory was also drawn on throughout this data collection/analysis in order to make sense of the findings. Finally, the thesis returned to the literature in order to situate the empirical findings within a broader theoretical context. Figure 2.2 illustrates this approach.

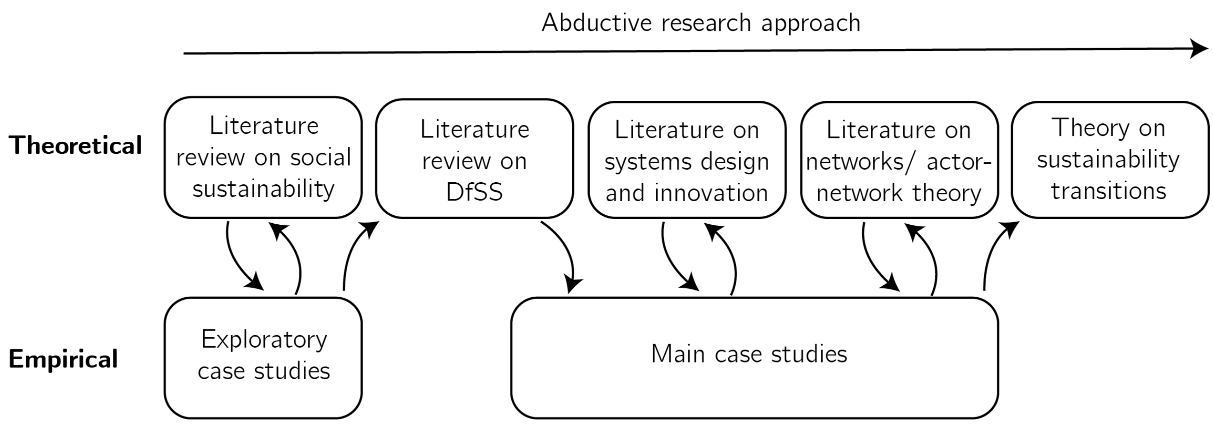

Figure 2.2– Overview of the abductive research approach used in this study

2.4 Choosing the case study strategy

Having selected a pragmatic and abductive approach, different strategic options were available for this study: grounded theory, action research, ethnography and the case study.

Grounded theory seeks to develop new theories from empirical data where no existing hypotheses exist (Glaser & Strauss, 1968). It relies on the researcher setting aside theory so that substantive theory can emerge from the data (Creswell, 1998). Considering the challenges of defining social sustainability and given the recent efforts in this field, it was decided that a conceptual framing was necessary before investigating the empirical data. On this basis it was decided that grounded theory was unsuitable for this research.

Ethnography provides detailed descriptions of social groups or systems and requires that the researcher is immersed in that group for an extended period of time (Hammersley & Atkinson, 1995). Whilst this strategy can offer rich interpretations, it risks that on one hand the researcher might not be accepted by the group and on the other hand that the researcher might become too assimilated (Creswell, 1998). Although the latter issue was less of a concern given the pragmatist position, it was decided for practical reasons that this strategy was too time consuming and data intensive for the constraints of this doctoral study.

Action research is a collaborative inquiry between researchers and practitioners to solve a specific problem (E. Bell et al., 2018). The aim of the research is to create new knowledge and to improve practice through repeated action, evaluation and analysis (Riel, 2019). As social sustainability is considered to be an ill-defined 'wicked problem'[5] it was decided that action research was not suitable for this study.

Given the elimination of these strategies, a multiple case study was selected as a suitable approach. A case study provides a detailed description of a phenomenon in its real-world setting and it is particularly valuable when the boundaries between the phenomenon and its context are difficult to separate (Yin, 2018 p. 15). It uses multiple sources of data, including interviews, direct observations, documentation, archive records and physical artefacts in order to converge or 'triangulate' findings (Yin, 2018 p. 114). Compared with other methods, such as surveys or experiments, the case study is well suited to explaining the causal links in data and can accommodate greater complexity (Yin, 2018 p. 18).

[5] A wicked problem is extremely challenging to solve because it is difficult to define, contradictory and often includes changing requirements. There may be no single solution, and it is hard to measure success (Rittel & Webber, 1973).

It is important to note that the case study is not intended to be a sample but it provides an opportunity to enrich theory (Stake, 1995 p. 443). Case study research is therefore not particularly concerned with generalisation but instead seeks to provide new insights into a particular issue (ibid). In this vein, (G. Thomas, 2010) argues that the case study should allow for "flashes of inspiration" that are not constrained by the quest for generalisation. As a strategy it has become increasingly common-place in the social sciences and has also been well used alongside abductive approaches (Creswell, 1998; Dubois & Gadde, 2002; G. Thomas, 2010).

In this thesis exploratory case studies were conducted prior to the main case studies to build up an understanding of the problem (Yin, 2018 p. 108). A multiple case study design was selected to provide robust and compelling evidence (Baxter & Jack, 2008; Herriott & Firestone, 1983). In both the exploratory and main study, the case is the DF4D project. The DF4D project here refers to ongoing interventions that aim to alleviate humanitarian and development problems. It is considered to include the entire project lifecycle, that encompasses the stages of product development, delivery and implementation. The context of these cases includes the organisational and humanitarian/development landscape, within which DF4D projects take place.

2.5 Mixed methods research

Mixed method research refers to the application of both quantitative and qualitative data collection and/or analysis methods (Johnson & Onwuegbuzie, 2004; Tashakkori & Creswell, 2007). It supports the examination of complex research questions and can provide a stronger evidence base than any one method (Yin, 2018 p. 63). Furthermore, if different methods are used and produce similar conclusions, then this convergence can increase confidence in the reliability of the findings (Morgan, 2014a p. 69). Combining qualitative and quantitative methods can also help to provide additional coverage, when different types of data can "*reveal different aspects of what is being studied*" (Denzin, 2010).

In this thesis, a purely pragmatic approach to using mixed methods research was adopted by asking: 'what works?' and 'what difference would it make to do research in another way?'. Based on this assessment, it was decided to collect qualitative data and to apply both quantitative and qualitative techniques to analyse this data. Decisions as to which method was most appropriate were based on the requirements of each stage of the research. This resulted in mainly qualitative analysis techniques being used, with some quantitative analysis in the main case study. Quantitative analysis of qualitative data is common-place in fields such as psychology and criminology and has also been applied to other domains in the social sciences (Bernard, 1996; Natarajan, 2006; F. Young, 1981). Qualitative analysis can offer rich, detailed descriptions of phenomena, whereas quantitative analysis can reveal important patterns in the data (Creswell & Creswell, 2018).

2.6 Data collection and analysis

Table 2.1 provides an overview of the research design, highlighting the data collection and analysis methods used in each chapter. In the following section a summary of the methods will be provided. A more detailed description of the methods will be presented in the relevant chapters for readability. This purpose of this section is to explain why the selected methods were used and to demonstrate the methodological consistency throughout the thesis.

Table 2.1 – Overview of the research design

	Chapter 3	**Chapter 4**	**Chapter 5**	**Chapter 6**
Objectives	To establish whether social sustainability is missing in DF4D.	To develop a conceptual understanding of DfSS.	To investigate DfSS in DF4D using an analytical approach.	To investigate DfSS in DF4D using a critical systems approach.
Guiding questions	1a. Is social sustainability missing in DF4D?	1b. What is currently known about DfSS?	1c. How to DfSS in DF4D?	1c. How to DfSS in DF4D?
Data collection	– Literature review on social sustainability. – A multiple case study of fourteen DF4D projects.	– Systematic literature review of sixty-four articles on DfSS.	– A multiple case study of three DF4D projects in the healthcare sector. - Thirty-seven interviews with designers, project managers, users and other stakeholders. - Direct observations. - Secondary data (reports, news etc).	– A multiple case study of three DF4D projects in the healthcare sector. – Three workshops to map the networks of the case studies using Designet toolkit.

Data analysis	Qualitative.	Qualitative.	Qualitative.	Mixed methods.
Outcome	– Validation that social sustainability is missing in DF4D projects and that designers lack adequate means to address this.	– A theoretical foundation for thesis.	– DfSS framework to support DF4D projects in planning and evaluation stages. – Evaluation of three DF4D projects using DfSS framework.	– Designet, a proposal for a toolkit to advance DfSS in DF4D projects. – A network analysis of three DF4D projects, revealing important insights for DfSS.

In Chapter 1 the historical failure of technology projects in the aid sector was highlighted. It was suggested that social sustainability could be a key gap in DF4D, and that design could help to promote social sustainability. This research aimed to first validate that social sustainability is indeed a problem in DF4D. Given the sparse literature on DF4D, it was decided to gather empirical evidence by conducting multiple case studies. Literature on social sustainability was collected to help analyse the data. To establish the scale of the problem, it was decided to review a wide range of DF4D projects. Using a similar approach to maximum variation sampling (Patton, 2002 p. 35), fourteen DF4D projects were included in this exploratory study. Table 2.2 provides an overview of the case studies.

Table 2.2 – Overview of the case studies in the exploratory study

Case study	**Organisations**	**Digital fabrication tool**	**Location of manufacture**
1. Spares/medical supplies	3D4MD, Médecins San Frontières	3DP	East Africa
2. Arm prosthesis	3D Life Prints	3DP	East Africa
3. Medical shoe	AB3D, TechforTrade	3DP	Kenya
4. Stethoscope	Glia	3DP	Gaza
5. Tourniquets	Glia	3DP	Gaza
6. Vacuum pump spare part	Field Ready	3DP	Nepal
7. Air supply disk for cookstove	Field Ready	3DP	Nepal
8. Reconstruction housing model	Field Ready	Laser cutting	Nepal
9. Socket for a leg prosthesis	Biomedical Engineering and Technology Innovation Centre at Indian Institute of Technology-Bombay	3DP, CNC	India
10. Arm prosthesis	Médecins San Frontières	3DP	Jordan

11. Arm prosthesis	Not Impossible	3DP	South Sudan
12. Hand washing device	Oxfam	3DP	Lebanon
13. Arm prosthesis	Victoria Hand Project	3DP	Nepal, Cambodia
14. Microscope	Waterscope, STIClab, Digital Blacksmiths	3DP	Kenya, Tanzania

Having validated that social sustainability was being overlooked in DF4D and that designers lack adequate means to address this, attention was turned to the role of design. A systematic literature review was conducted to build up an understanding of DfSS. Systematic reviews help to summarise existing knowledge and position new research activities (Kitchenham, 2004). This analysis provided a robust theoretical foundation for the subsequent main study.

The main study consisted of a smaller, more homogenous multiple case study (Suri, 2011). Criterion sampling was used to identify ongoing projects using DF4D in the Global South that collectively represented a similar industry. As the majority of projects in the exploratory study were focused on healthcare, it was decided to narrow the search to DF4D projects in the healthcare sector. Practical considerations were also taken into account and foreign travel advice from the UK Foreign and Commonwealth Office (FCO) was consulted. For example, one project was excluded from the shortlist because it would not be possible to travel to Gaza as the FCO advise against all travel to the region. One project which was shortlisted from the exploratory study was also excluded because researcher was denied access by the organisation (Médecins San Frontières). This inclusion/exclusion criteria finally led to the identification of three suitable case studies (see Table 2.3). Overall, preparing for these case studies took many months of planning that involved liaising with different organisations to obtain consent and to arrange logistics for the field work. This was particularly challenging given the transnational remit of the work.

In the main study, two independent but complementary ways were taken to investigate DfSS in DF4D. The first adopted an analytical approach that is based on the search for simplicity. The second used a critical systems approach that embraces complexity. In each of these approaches, data was collected and analysed in different ways. The analytical approach collected data from a wide range of sources including interviews, reports, documents and observations. Thematic coding of the literature and case study data was conducted to develop a framework to support DfSS in DF4D projects. Each of the case studies was also evaluated using the framework. The critical systems approach focused on mapping the networks of the DF4D projects. An initial toolkit, Designet was developed as a participatory and designerly way of representing these networks. These representations were analysed using qualitative and quantitative methods based recommendations by Venturini & Latour (2009). In this thesis it is argued that both analytical and critical systems approaches are necessary but neither are sufficient alone. Together, they provide independent but complementary ways of understanding the same phenomenon.

In Case Studies 1 and 3 all the interviews were conducted in English because of the participants' fluency. In Case Study 2, all the interviews with end users and beneficiaries were conducted in Hindi, the official language of India. Translation assistance was provided by an experienced translator who was identified through personal networks because of her familiarity with the context and her experience coordinating research. Ensuring that translators are fully informed of the purpose of the research is a key part of planning research in the Global South (Corsini, Aranda-Jan, Henderson, et al., 2019). Prior to the research trip, two skype calls were arranged with the translator to discuss the research background, aims and questions. A research plan and the participant consent forms were shared with the translator in advance to be translated into Hindi. Prior to starting the data collection, a face to face meeting was also arranged in India to discuss the data collection plan in detail.

Table 2.3 – Overview of the main case studies

Case study	Organisations involved	Digital fabrication tool	Location
1. Otoscope	Field Ready*	3D printing	Nepal
2. Leg prosthesis	Biomedical Engineering and Technology Innovation Centre (BETiC) at Indian Institute of Technology-Bombay (IIT-B)*, Ratna Nidhi Charitable Trust (RNCT) Mumbai, Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS) Jaipur	3D printing/ CNC milling	India
3. Suction pump machine	FabLab/MakerSpace Nairobi*, Kenyatta National Hospital (KNH), Concern Worldwide, Phillips Foundation, UNICEF	3D printing/ CNC milling	Kenya

* Main organisation leading the project

2.6.1 Ethical issues, approval and consent

Any research plan should take steps to anticipate and actively address ethical issues in the research (Creswell & Creswell, 2018 p. 91). This is particularly important for research that includes vulnerable groups (Sieber, 1992). It is recommended that the researcher constantly reflects on ethical issues throughout the data collection, analysis, reporting, sharing and storage (Creswell & Creswell, 2018 p. 91).

Prior to starting the study, an ethical approval form and risk assessment form was submitted to the Department of Engineering for review. This form included a full description of the: purpose of the research; involvement required from the participants; risk of physical, psychological, social and economic harm; process for obtaining consent; and, arrangements for ensuring anonymity and confidentiality. Full approval was confirmed before the data collection started.

An informed consent form was created for all the participants based on the World Health Organisation's template for conducting a qualitative study[6]. This form used straightforward language to explain: the purpose of the research; the type of research intervention; reasons for participant selection; procedures; duration; risks; benefits; confidentiality; rights to refuse; and, key contact details of the researcher. It also included a certificate of consent for the participant to confirm that they had understood the information and voluntarily consented to participate in the study. In Case Study 3, the informed consent forms were translated into Hindi prior to the data collection by an experienced translator. Where participants had limited or no literacy, the informed consent form was explained orally and verbal consent was obtained instead of written consent. In Case Studies 1 and 2, all the interviews were conducted with fluent English speakers and written consent was obtained.

During data collection, attention was paid to ethical issues. The researcher was respectful of the organisations that they visited and tried to minimise the disruption caused by their presence (Creswell & Creswell, 2018 p. 93). For example, short interviews were conducted with clinical staff at Kenyatta National Hospital because the researcher was aware of their busy schedules. The researcher was also reflective and noted how their presence could lead to power imbalances (Kvale, 2007). For example, in Case Study 2, some people receiving prostheses at BMVSS asked the researcher whether they could financially support their care or advise them on the best care. In this case, it was important to be transparent and to remind the participants about the purpose of the study. The renumeration of participants involved in the study was discussed with the

[6] https://www.who.int/ethics/review-committee/informed_consent/en/

partner organisations, following recommendations from Corsini, Aranda-Jan, Henderson, et al. (2019), however this was decided against based on their advice.

Whilst analysing the data, the researcher was also conscious of potential ethical issues. Creswell & Creswell (2018) raise the concern that researchers can fall into the trap of only disclosing results that are favourable to the views of participants or the researcher. They also point out the challenge of 'taking sides' and disregarding contradictory evidence. As much as possible, the researcher adopted a critical perspective and used as many sources of data as possible to help mitigate this risk. In the field notes, the beliefs and motivations of different stakeholders were identified by the researcher to add context to their points of view. This provided a useful way of questioning what the interviewees reported.

A plan for data storage was a created to protect the participants' personal data. For potentially vulnerable groups, such as ends users and beneficiaries, all the data collected was completely anonymous so that they could not be identified. Otherwise the data was fully pseudonymised, meaning that the data cannot be attributed to a particular individual without using additional information. All interview recordings were deleted after being transcribed verbatim. Photographs, audio transcripts, field notes and other documents were stored on a secure folder in Google Drive to mitigate against the accidental loss of data, which can cause unintended harm to participants (GDPR, 2020). All other copies were deleted from personal devices after they were imported to MAXQDA, a data analysis software. This data is only accessible by the researcher, according to the agreement made with the participants. After the PhD is completed, this folder will be reviewed and any data no longer needed will be erased. Based on recommendations from Sieber (1992) this data will be kept for five years after the thesis is submitted. The interview questions that were used to obtain this data will be uploaded to the University of Cambridge data repository via Sympletic Elements and will remain accessible.

2.6.2 Quality of the study

The quality of any given design can be judged according to the logical tests of construct validity, internal validity, external validity and reliability (Gibbert et al., 2008; Kidder et al., 1986; Yin, 2018). The following section will address how each of these tests are handled in this thesis.

Construct validity means the "*degree to which a test measures what it claims, or purports, to be measuring"* (Brown, 2000). In this sense, construct validity can be thought of as the overall validity of a study, as it examines the appropriateness of a judgement based on the observations made (Yin, 2018 p. 43). To deal with construct validity, a number of key steps were taken. First, multiple sources of data were used to triangulate the findings. Second, the main study was informed by the findings in the exploratory study. Third, the main findings were shared with participants, who were given an opportunity to comment on them and suggest changes (Miles & Huberman, 1994).

Internal validity is a particular concern for explanatory studies that attempt to define the causal relationships within a case study (Yin, 2018 p. 45). Internal validity can be threatened by history (i.e. events in the wider context that affect the case study), maturation (i.e. changes in participants during the case study) or confounding effects (i.e. a third unknown variable). To mitigate against this concern as much as possible, pattern matching was used to cross-check the findings between the cases and the literature to help maintain internal validity (Trochim, 1989).

External validity is concerned with the generalisability of a case study (Yin, 2018 p. 45). In this thesis the potential for analytic generalisation is emphasised over statistical generalisation. Whereas statistical generalisation is concerned with making predictions from data about a population, analytic generalisation makes inferences about the likely transferability of the findings (ibid). In other words the aim is to create theoretical propositions, not universal truths. Nonetheless external validity is considered in the selection of a multiple case study design which offers some evidence of replication. The main study is also constructed using two complementary approaches, providing coverage against the limitations of any single approach (Morgan, 2014b).

Finally, reliability is the consistency or repeatability of the research findings (Creswell & Creswell, 2018). Sometimes reliability is defined as the ability for another researcher to follow the same procedures and repeat the study to "*arrive at the same findings and conclusions*" (Yin, 2018 p. 46). To enable this, the case study protocol and data has been made as transparent and open as possible (without exposing participants to potential harm). Whilst the researcher expects that another investigator could replicate this research, it is not expected that this would result in the same findings (Robson, 2002 p. 168). The way we understand and make sense of the world is shaped by our beliefs: "*when you think differently, you perceive differently*" (Linderman, 2012). In this thesis, care is taken to alert the reader to the researchers' background, which may serve as both a source of bias and as an analytical tool (Robson, 2002).

2.7 About the researcher

In 2014 I graduated in Engineering (BA, MEng) from the University of Cambridge and continued to study 3D Design (Foundation Diploma) at Central Saint Martins, University of the Arts London. Shortly after I graduated, I worked as a designer at a not-for-profit technology company to develop solutions to improve maternal healthcare in the Global South. I then joined a global management consulting company, where I translated design thinking and human centred design methodologies into technology projects for the public and private sector. These experiences influenced my thinking and during this time, I that realised my interest lay not just in the problem-solving activity of designing new technologies, but in the problem-reframing activity of researching and understanding the cultural and social practices that underlie these technologies.

My particular interest in this PhD topic started with a visit to the Design Museum in London, although my commitment to activism and humanitarian causes began much earlier. During this visit to the Design Museum, I took note of a 3D printed prosthetic arm developed for people in a war torn region in South Sudan, that had been shortlisted for the Designs of the Year 2015 Award. I was intrigued and wanted to understand more about the potential of digital fabrication to help people in challenging contexts. It was during my PhD that I started to reflect on my own education and experiences to question what Linderman (2012) describes as The Belief. The Belief is a way of thinking that is almost taken for granted in the North; the legacy of the Enlightenment that the only way of knowing is through the scientific method. It is this Belief that has shaped humanitarian and development interventions since the post-war era, and it is the same Belief that undoubtably influenced the inclusion of a 3D printed prosthetic designed for use in South Sudan – one of the poorest countries in the world – in a gallery that is now located in Kensington and Chelsea, the wealthiest five square miles in the United Kingdom, the fifth richest country in the world. Simply, it is the assumption that technology can only be a good thing to help the "poor".

Apart from my PhD, I have lectured on Product Design to 3rd year Engineering undergraduates at the Institute for Manufacturing, University of Cambridge. I have tutored students in their design projects to tackle the United Nations' Sustainable Development Goals and to "Manufacture a

Better World" (the motto of the Institute for Manufacturing). I have also helped to tutor or assess modules on Design Thinking at the Judge Business School and Sustainable Engineering, Engineers in Society and Technical Drawing at the Department of Engineering, University of Cambridge. I am part of a design initiative at the University of Cambridge that works with partners in Kenya to upcycle plastic waste into building materials. This project has received multiple awards from the Winton Programme for the Physics of Sustainability, Smart Villages, Cambridge Malaysian Education and Development Trust and the Cambridge Creative Circular Plastics Centre (CirPlas).

During my research I have constantly reflected on my role as a researcher and asked myself what qualifies me to write on this topic. As an Italian-British researcher educated in the UK, am I just another 'white saviour' reaffirming the "invention of development" as Escobar (2011 p. 24) puts it. The connection between this research and the colonial legacy of Great Britain is not lost on me, especially given the fact I conducted my field work in two countries that were formerly part of the British Empire. I am grateful for the work of Arturo Escobar for helping to shape my reflections on this. In this research I am sensitive to the views of the affected actors in the system. I position myself as an ally, not speaking for, but putting a spotlight on their accounts. In doing so, I hope that this research can help build a bridge between the perspectives of the people who are affected by DF4D, and the global apparatus that pursues these projects which includes non-governmental organisations, donors, global innovation actors, researchers and innovators. Everything we write is inevitably from a particular perspective, but to the extent possible I have tried to look at things from different points of view to dispel the idea that there is one 'right' way (as in The Belief). I view my work as just one contribution to this field, that I hope will grow to include a rich and varied set of perspectives, that especially includes the scholarship of researchers from the South.

2.8 Summary

This chapter has provided a description of the research methodology and design that guides this thesis. To begin with, pragmatism was introduced as the research paradigm. Underlying this, is the belief that the researcher and the subject cannot be separated, just as knowing cannot be separated from doing. It was also put forward that there are different ways of looking at the same problem, and that different approaches will naturally elicit different understandings of the same phenomenon. For this reason the main study adopts both an analytical and a critical systems approach, using mixed methods to analyse qualitative data. The main study is informed by an exploratory study, both of which include data from multiple case studies of DF4D projects. Each stage of the research required evaluation of which data collection and analysis methods were most suitable and as a whole, the research design was checked to maintain methodological consistency. This chapter has provided a valuable methodological foundation to guide the thesis. The following chapters will include more detailed descriptions of the methods for readability. This thesis continues with the exploratory study in the next chapter.

Chapter 3 Is social sustainability missing in DF4D?

3.1 Introduction

Chapter 1 discussed the historical failure of technology projects in the aid sector. It reflected on the problems of the ICT4D movement to question how DF4D might avoid the same fate. It was suggested that social sustainability could be a key gap in DF4D that needs to be addressed. Chapter 2 introduced the research methodology and design that shapes this study. Notably it identified that this research will follow a pragmatic approach, and it will include data from multiple case studies. Given the sparse literature on DF4D, this chapter aims to investigate the proposition that social sustainability is lacking by gathering empirical data about DF4D projects. To help frame this exploratory study, Section 3.2 provides an initial summary of literature on social sustainability to clearly define this concept. Section 3.3 explains the methods used. Section 3.4 presents the results of the multiple case study. Section 3.5 discusses the implications of these findings. It provides an important foundation for this thesis, by concluding that by and large social sustainability is not being adequately addressed in DF4D.

3.2 What is social sustainability?

It is widely accepted that sustainability must include social, economic and environmental dimensions (Elkington, 1999). Social sustainability is a cornerstone of sustainable development as it is concerned with the wellbeing of societies now and in the future (I. Khan, 2020; Vallance et al., 2011). Despite its importance, it is often overlooked within sustainability research (Chick, 2012; Fuad-Luke, 2009; Joyce & Paquin, 2016; Missimer et al., 2017a; Zink, 2014). Sustainability discourse has mostly focused on environmental issues, to the degree that sustainability is often used interchangeably with environmental protection (McKenzie, 2004; Opp et al., 2014).

Moreover, many integrated sustainability models have placed a disproportionate focus on environmental factors, compared with social factors (Colantonio, 2009). This is problematic because several studies have shown that people can only begin to actively address environmental issues once their basic needs have been met (Bhatti & Dixon, 2003; Burningham & Thrush, 2003). According to this scholarship, social sustainability is a precursor to environmental sustainability (Vallance et al., 2011).

The economic dimension of sustainability has also largely dominated perspectives in the aid sector (Marais, 2015, 2011). As noted in Chapter 1, sustainability in the aid sector is often defined as "*measuring whether an activity or impact is likely to continue after donor funding has been withdrawn*" (ALNAP, 2007 in Haavisto & Kovács, 2014). This economic lens has been used in market-based approaches to designing for the Bottom of the Pyramid (BoP) (Prahalad & Hart, 2002; Prahalad & Ramaswamy, 2004). These approaches seek to position vulnerable populations as consumers, instead of victims. However, there is little differentiation between essential items (e.g. food, medicines) and non-essential items (Jaiswal, 2008; Karnani, 2006). To this extent, 'development' is a common synonym for 'economic growth'. The clear limitations of this approach highlight that the social dimension of sustainability requires greater attention to protect the wellbeing of societies.

One reason that social sustainability has been largely neglected is that there is a lack of clarity about what it means (E. Becker et al., 1999; El Ebrashi, 2013; Griessler & Littig, 2005; McKenzie, 2004). As a concept it is intrinsically complex as it deals with social values which are not easily quantified and are difficult to separate from their context (Bebbington, & DIllard, 2009; Geibler et al., 2006; Spangenberg & Omann, 2006). For this reason social sustainability has even been described as a 'wicked problem' (McMahon & Bhamra, 2015). Wicked problems are extremely challenging to solve, include changing requirements and no single solution may exist (Rittel & Webber, 1973). It is further reported that many definitions of social sustainability are ambiguous and there is a tendency towards discussing its related themes, rather than defining it clearly (McKenzie, 2004). Furthermore, studies on social sustainability are often isolated between disciplines (Colantonio, 2009). For example, its popularity in urban studies has led to the development of many specific indicators being created for the built environment (Ahmad & Thaheem, 2017; Shirazi & Keivani, 2019). Overall, this has led to views that the field is 'fragmented' (Weingaertner & Moberg, 2014) and that social sustainability itself is a 'concept in chaos' (Vallance et al., 2011).

Despite these concerns, social sustainability seems to be a promising area of research that is turning a corner. In the last few years, there has been a rapid growth in publications on social sustainability (see Figure 3.1) and its new-found recognition is contributing to its conceptual and operational development (D'Eusanio et al., 2019; R. Khan, 2016; Smyth & Vanclay, 2017).

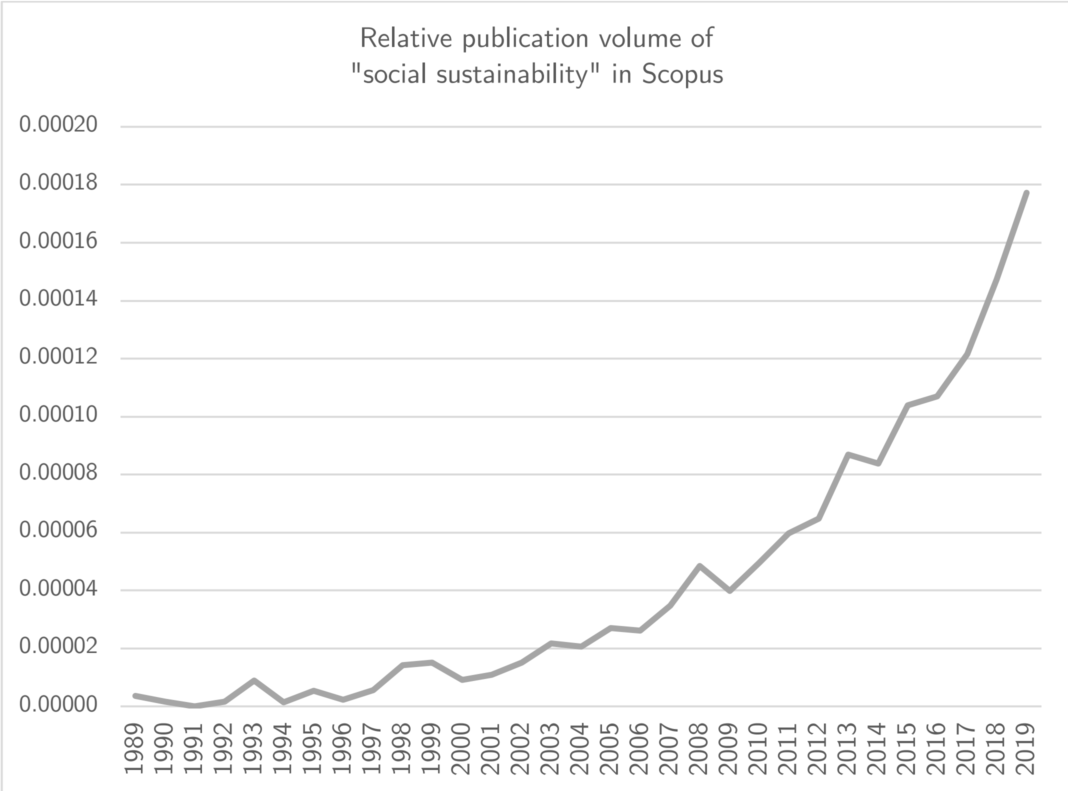

Figure 3.1 – Relative publication volume of social sustainability as found in Scopus collection

It has also been argued that a plurality of definitions is in fact needed to recognise the different contexts in which social sustainability is required (Davidson, 2010; Dempsey et al., 2011). Among the various definitions in the literature, it is clear that social sustainability prioritises the human values of wellbeing, now and in the future. I. Khan (2020) describes social sustainability as "*social factors that are essential for achieving long-term, social wellbeing*", McKenzie (2004) calls it "*a life-enhancing condition within communities and a process that can achieve*" and Missimer et al. (2017b) define it as the preservation of the social system, where "*people are not subject to structural obstacles to: health, influence, competence, impartiality and meaning-making*". Griessler & Littig (2005) centre the discussion on human need by establishing that "*social sustainability is given, if work within a society and the related institutional arrangements satisfy an extended set of human needs*". Table 3.1 provides some definitions of social sustainability found in highly cited articles. Among these numerous definitions, this thesis broadly refers to social sustainability as the preservation of the social system in which people are not subject to structural obstacles (i.e. barriers that are systemically rooted in social institutions). Put simply, social sustainability is concerned with the human wellbeing and flourishing of societies now and in the future.

Table 3.1 – Definitions of social sustainability found in highly cited documents

Source	Definition of social sustainability
Sachs (1999)	A strong definition of social sustainability must rest on the basic values of equity and democracy, the latter meant as the effective appropriation of all human rights – political, civil, economic, social. and cultural – by all people.
Barron & Gauntlett (2002)	Social sustainability occurs when formal and informal processes, systems, structures and relationships actively support the capacity of future generations to create healthy and liveable communities. Socially sustainable communities are equitable, diverse, connected and democratic and provide a good quality of life.
McKensie (2004)	A life-enhancing condition within communities and a process that can achieve it.
Griessler & Littig (2005)	… a quality of societies. It signifies the nature-society relationships, mediated by work as well as relationships with the society. Social sustainability is given, if work within a society and the related institutional arrangements satisfy an extended set of human needs [and] are shaped in a way that nature and its reproductive capabilities are preserved over a long period of time and the normative claims of social justice, human dignity and participation are fulfilled.
Bradley & Lee (2005)	For a community to function and be sustainable, the basic needs of its residents must be met. A socially sustainable community must have the ability to maintain and build on its own resources and have the resiliency to prevent and/or address problems in the future.
Dempsey et al. (2011)	Like the concept of sustainability, social sustainability is neither an absolute nor a constant. Social sustainability has to be considered as a dynamic concept, which will change over time (from year to year/decade to decade) in a place. This may come about through external influences: for example, social cohesion and interaction may increase, prompted by changes in local authority service delivery or the threat of airport expansion.
Missimer et al. (2017b)	In a socially sustainable society, people are not subject to structural obstacles to: (1) health, (2) influence, (3) competence, (4) impartiality and (5) meaning-making.

Within the literature, whether social sustainability refers to the social conditions needed for the development of society or the need to sustain certain structures in society is raised as a point of confusion (Colantonio, 2009; Sachs, 1999). In response, Vallance et al., (2011) argues that social sustainability in fact comprises of three separate approaches. 'Development sustainability' aims to meet basic needs and reduce poverty, 'bridge sustainability' focuses on behaviour change for bio-physical environmental goals and 'maintenance sustainability' attempts to preserve socio-cultural patterns. Within this thesis, 'development sustainability' is especially pertinent because of its emphasis on need fulfilment. However, all three of these dimensions are inherently interconnected. In this sense, I return to McKensie's (2004) proposition that social sustainability is both a life-enhancing condition (an end) and a process for achieving it (a means). Thus, it can certainly be said that one state is more or less socially sustainable than another.

In the last few years, there have been some important works that have attempted to synthesise knowledge in the field. Lee & Jung (2019) have undertaken a semantic network analysis to map the conceptual development of social sustainability. They argue that its conceptual scope has evolved but it is now stabilising to focus on human factors, related to quality of life. R. Khan (2016) conducted a systematic literature review to identify key themes of social sustainability, related to wellbeing, quality of life, social coherence, social justice, democracy, human rights, diversity, social inclusion, social capital, the decline of poverty and the preservation of socio-cultural patterns (see Table 3.2). Eizenberg & Jabareen (2017) provide a new conceptual framework for social sustainability based on the interrelated concepts of equity, safety, eco-prosumption and urban forms. In their work, equity refers to equal distribution between current and future generations, safety is focused on wellbeing and the prevention of harm, eco-prosumption refers to people's right to ethical production, and urban forms represent the products or services that promote social sustainability. Some authors have focused on particular dimensions of social sustainability. For example Langergaard (2019) emphasises participation as a key dimension of social sustainability in order to explore its constituent themes.

With respects to measuring social sustainability, there have been several attempts to develop social sustainability into an operational concept (Hutchins & Sutherland, 2008; I. Khan, 2020). However it is noted that indicators have been generally hindered by a lack of conceptual clarity in the field (Geibler et al., 2010; Vallance et al., 2011; Khan, 2020). Furthermore, many aspects of social sustainability are qualitative and inherently difficult to measure. Colantonio (2009) notes that 'hard' social sustainability themes such as employment and poverty alleviation are being increasingly complemented by 'soft' themes such as happiness, social cohesion and sense of place. In some cases, social factors have been incorporated into environmental impact assessment tools by 'stretching' their coverage. However, these do not seem to adequately address social concerns (Therivel, 2013). Colantonio (2009) also notes that many social impact assessments that have been used to measure social sustainability, were not originally designed for this purpose. He argues that these social impact assessments often neglect the temporal scales that sustainability demands.

More recently several authors have focused explicitly on the development of a social life cycle assessment. For example, Benoît et al. (2010) create a set of indicators for assessing the social sustainability of products. They consider indicators from across the product supply chain, related to workers, consumers, the local community, society and other value chain actors. Jørgensen et al. (2008) focus on indicators related to human rights, working conditions, society and product responsibility. Dreyer et al. (2006) considers how social impacts can affect companies, local communities, society and global society. Schmidt et al. (2008) analyses how social, human, physical and natural capital are integrated into a life cycle assessment. A more recent review by Wu et al. (2014) summarises the different social impact assessment tools that have been developed. They show many common dimensions, related to workers, consumers, local communities, society and the value chain. Overall, most tools have been developed for a specific industry, and thus present context-specific indicators.

Table 3.2 – Themes of social sustainability adapted from R. Khan (2016)

Themes of social sustainability	
Basic needs and quality of life	Participation
Human health and wellbeing	Social coherence
Social justice and equity	Social capital
Employment	Social inclusion
Decline of poverty	Diversity
Education and training	Sense of place and belonging
Human dignity	Safety and security
Human rights	Community resilience
Preservation of socio-cultural patterns and practices	

3.3 Methods

The aim of this exploratory study is to test the proposition that social sustainability is a gap in DF4D. Given the sparse literature on DF4D, it was decided to gather empirical evidence. To begin with, DF4D projects were identified using online searches, news articles, snowballing and personal networks. It was decided to use maximum variation sampling to maximise the diversity of case studies and identify important shared patterns (Patton, 2002). This selection process focused on 'what', 'where' and 'who' questions. Efforts were made to identify DF4D projects representing a range of applications in healthcare, energy, education and, water and sanitation. A wide geographical area was examined to identify as many projects as possible in the Global South.

It was decided to select case studies from a range of different types of institutions (e.g. charities, public and private institutions). To be considered as a case study, the project had to be developed with end use in mind. This meant that any prototypes/pilot projects were excluded from the study. Once a shortlist of projects was established, organisations were contacted between July 2017 and May 2018. This resulted in fourteen case studies being included in this exploratory study.

To gather data on the case studies, semi-structured interviews were conducted with designers, engineers and managers at the organisations involved in the DF4D projects. Secondary data sources were also reviewed, including reports, websites and press articles. To collect this data, the first page of Google search and Google news results were reviewed using a combination of the organisation's name and project description as search terms (e.g. "Not Impossible" "Project Daniel" or "3D LifePrints" "arm prosthetic"). Whilst searching online, the researcher was logged into their Google account, and there is the potential limitation that their digital shadow may have shaped the results retrieved. Overall, the researcher believes this impact to be minimal as the total number of Google news results was relatively low. Interviews were conducted via skype or in person, with each interview lasting between 60-90 minutes. All the interviews were recorded with the participants' consent and transcribed verbatim. This was complemented by detailed note-taking by the researcher during the interviews. Where possible, interviews were carried out with multiple people involved in the DF4D project, to validate the data and improve its robustness through triangulation (Denzin, 1978). Some follow up interviews were conducted to gather additional data, especially from ongoing projects. In total, twenty-six interviews were conducted with twenty-one interviewees.

Although key questions were identified in advance, the interviews were fluid and discursive in nature. Emphasis was placed on gathering important information instead of asking a rigid checklist of questions (Fylan, 2005). The interviews addressed the following main sections. In the first part, interviewees were asked to describe the DF4D project, including the product that they had developed or were developing. In the second part, interviewees were asked about the aims and (if possible) actual impact of the project. Here, the key themes of social sustainability were used to help elicit useful information. In the third part, interviewees were asked to reflect on the factors that influenced their outcomes.

Before formally starting to analyse the data, the following information was documented for each of the cases: organisations involved, digital fabrication tools used, location of manufacture, project dates and stage of product development. Table 3.3 summarises this information for the case studies. It shows that DF4D is an emerging field of interest among different types of organisations, including international non-governmental organisations (NGOs), charities, social enterprises, makerspaces and research institutions. It also shows that many projects are in the stages of product development, with relatively few projects having been implemented.

To begin with data analysis, each of the projects was classified according to their overall impact. Heeks & Molla (2009) suggest that ICT4D projects can be broadly classified using five categories. Given the relevance of ICT4D to DF4D, it was decided that the following categories would also help to provide an initial evaluation of DF4D projects:

- **Total failure -** the initiative was never implemented, was implemented but immediately abandoned, or was implemented but achieved none of its goals.
- **Largely unsuccessful -** some goals were attained but most stakeholder groups did not attain their major goals[7] and/or experienced significant undesirable outcomes[8].
- **Partial success/partial failure -** some major goals for the initiative were attained but some were not and/or there were some significant undesirable outcomes.
- **Largely successful -** most stakeholder groups attained their major goals and did not experience significant undesirable outcomes.
- **Total success -** all stakeholder groups attained their major goals and did not experience significant undesirable outcomes.

Using this criteria, an evaluation of each of the cases was attempted. Some cases were not possible to evaluate as the projects were still ongoing and there was insufficient information on their actual impact. On this basis, case studies 4, 9, 10, 13 and 14 were excluded from further analysis. Among the nine remaining cases, six were categorised as total failures; one was a partial success/partial failure; and, two were deemed total successes.

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[7] Major goals are defined as the main objectives a group wanted to achieve with the DF4D project (which might related to outputs or impacts).

[8] Undesirable outcomes are unexpected outcomes that a group did not want to happen but which did happen.

It was then decided to evaluate these nine cases with respects to the themes of social sustainability identified in Table 3.2. Among the varied scholarship on social sustainability, it was decided to use the themes of social sustainability found in R. Khan (2016) as it was felt that this effort was very thorough and the most recent that the researcher could find. R.Khan (2016) derived these themes by analysing 91 publications as part of a systematic literature review on social sustainability. All the themes listed in their paper with more than two citing papers were included in Table 3.2.

All the interview transcripts were imported into MAXQDA, a data analysis software. A code hierarchy was created based on the themes of social sustainability. Line by line qualitative coding of the interview transcripts was then conducted to build up an understanding of how each case addressed the themes of social sustainability (Saldaña, 2015). Additional data, such as news reports and blog posts were also imported to MAXQDA for analysis. This process was intended to help with the retrieval of information for writing up the case studies. The researcher aimed to identify how each case related to the social sustainability themes, however in some cases not all of the themes were apparent in the data. The emphasis in the following section is to describe the cases, and to explain how the cases either positively or negatively contribute to the themes of social sustainability that are apparent in the data. This process of analysing the cases follows a similar approach to that taken by R. Khan (2016) to analyse the social sustainability of several frugal innovations. The following section will describe the case studies in detail to evaluate whether social sustainability is being sufficiently addressed in DF4D.

Table 3.3 – Overview of the exploratory case studies

Case study #	Organisations	Project	Digital fabrication tools	Location of manufacture	Project dates	Product development stage	Project impact assessment	Interviewees
1	3D4MD, Médecins San Frontières (MSF)	Spares/ medical supplies	3DP	East Africa	2018	Research	Total failure	CEO and designer, 3D4MD (01-01) Project manager, MSF (01-02)
2	3D Life Prints	Arm prosthesis	3DP	East Africa	2013 – 2016	Implementation	Total failure	CEO, 3D Life Prints (02-01)
3	AB3D, TechforTrade	Medical shoe	3DP	Kenya	2012 - 2014	Design and testing	Total failure	CEO and engineer, AB3D (03-01) Designer, AB3D (03-02) CEO, TechforTrade (03-03)
4	Glia	Stethoscope	3DP	Gaza	2017 -	Testing	?	CEO, Glia (05-01)
5	Glia	Tourniquets	3DP	Gaza	2017-	Implementation	Total success	
6	Field Ready	Vacuum pump spare part	3DP	Nepal	2016	Implementation	Partial success/ partial failure	Innovation Lead, Field Ready (06-01) Programme manager 2015-2016, Field Ready (06-02)
7	Field Ready	Reconstruction housing model	3DP, laser cutting	Nepal	2017	Design	Total failure	Programme manager 2016-2018, Field Ready (06-03)
8	Field Ready	Air supply disk for cookstove	3DP	Nepal	2017 -	Implementation	Total success	Designer, Field Ready (06-04) Monitoring & Evaluation, Field Ready (06-05)
9	Indian Institute of Technology-Bombay (IIT-B)	Leg prosthesis	3DP, CNC	India	2015 -	Design and testing	?	Project investigator & engineer, IIT-B (09-01)
10	Médecins San Frontières (MSF)	Arm prosthesis	3DP	Jordan	2016 -	Design and testing	?	Project manager and engineer, MSF (10-01)
11	Not Impossible	Arm prosthesis	3DP	South Sudan	2014 – 2016	Implementation	Total failure	Project manager, Not Impossible (11-01) Engineer, Not Impossible (11-02)
12	Oxfam	Hand washing device	3DP	Lebanon	2015	Design	Total failure	Project manager and engineer, Oxfam (12-01)
13	Victoria Hand Project	Arm prosthesis	3DP	Nepal, Cambodia	2013 -	Design and testing	?	COO, Victoria Hand Project (13-01)
14	Waterscope, STIClab, Digital Blacksmiths	Microscope	3DP	Kenya, Tanzania	2014 -	Design and testing	?	CEO and engineer, Waterscope (14-01) CEO and engineer, STIClab (14-02) Engineer, Digital Blacksmiths (14-03)

3.4 Main findings

3.4.1 Arm prosthesis by Not Impossible

In 2012 Mick Ebling, the founder of the non-profit Not Impossible read about the story of Daniel in an article. Daniel was a fourteen year old boy who had lost both his arms as a result of the civil war in Sudan. In the article Daniel describes the trauma of losing his arms and is quoted as saying: "*if I could have died, I would have*" (A. Perry, 2012). Mick Ebling was so moved by the story that he decided to find a solution. He organised a hackathon in California to experiment with 3D printing a prosthesis arm for Daniel. In a YouTube video, Mick Ebling describes the hackathon as "*an utter absolute failure*" (Talks at Google, 2015). Nonetheless he decided to travel to the Nuba Mountains in South Sudan the following month in November 2013. He successfully found Daniel, and a month later Daniel was able to feed himself using his 3D printed arm. Shortly after Not Impossible returned to California, leaving behind a 3D printer at a clinic in the community.

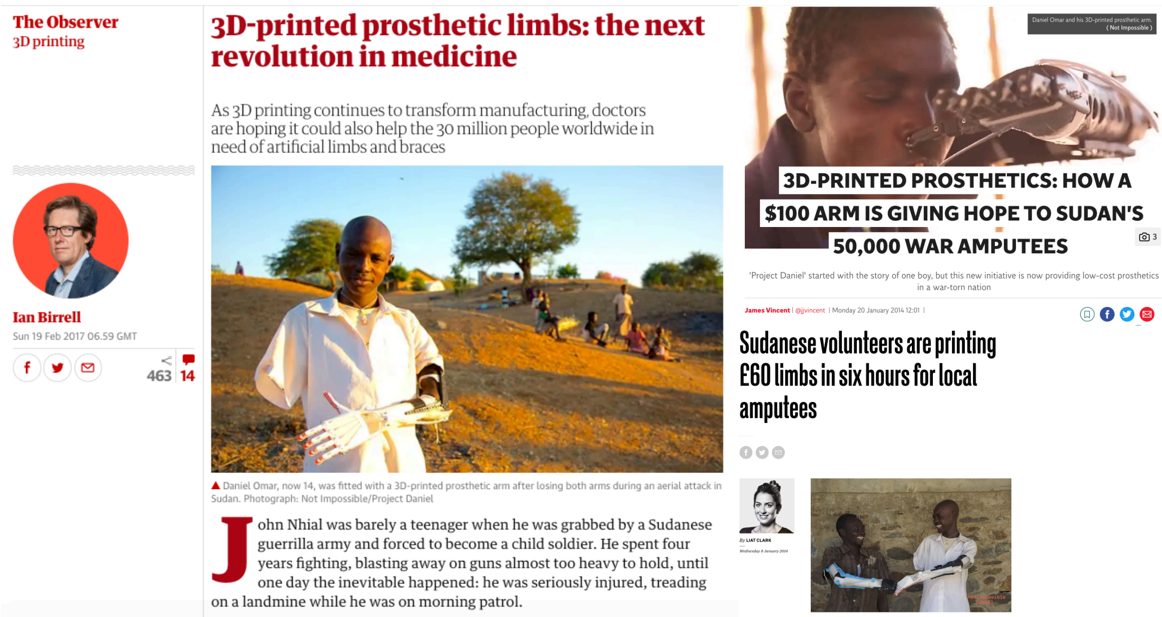

Figure 3.2 –Press coverage of Project Daniel in The Observer (Birrell, 2017), The Independent (Vincent, 2014) and Wired (L. Clark, 2014)

According to the literature, Project Daniel is a pioneering project that has transformed the lives of the community in the Nuba Mountains (Ibrahim et al., 2015; Maric et al., 2016). The project has received multiple awards and was nominated for the Design of Year 2015 Awards by the Design Museum (UK). News articles have described the project in various hyperbolic terms as 'transformational', 'life changing' and 'restoring humanity'. McCracken (2014) wrote in TIME magazine: "*it's hard to imagine any other device here doing more to make the world a better place.*" More recently, Bentley (2018) declared in Fortune magazine that Not Impossible "*has succeeded, significantly so, in changing the quality of life for multiple people with … limb amputation.*" Figure 3.2 highlights some of this press coverage.

Despite the fact that Project Daniel continues to be broadly reported as a success, the findings from this study suggest otherwise. Table 3.4 illustrates how Project Daniel addresses the different themes of social sustainability found in the literature. It clearly highlights that the project is lacking in multiple dimensions.

Table 3.4 – Evaluation of arm prosthesis by Not Impossible

Themes of social sustainability	**How project addresses the key themes of social sustainability**
Basic needs and quality of life	Prosthesis is a short-term fix that is too cumbersome for people to use after a while. No planning for long-term maintenance and repair.
Social justice and equity	Project aims to provide free prostheses for marginalised, rural population in South Sudan that otherwise cannot afford them.
Employment	Production of prostheses is an additional responsibility for clinical staff. No new employment is created.
Education and training	Very limited training on how to use 3D printers is provided. Local community are not well equipped to deal with the technological challenges.
Human dignity	Although initiative aims to restore human dignity, it creates false hope by providing a short-term fix.
Health and wellbeing	Focus is only on delivering a physical solution and mental trauma of amputees is not considered.
Participation	Community do not meaningfully participate in the design process. Users are only consulted for functional customisation of the prostheses.
Sense of place and belonging	Prosthesis is functionally customised, but not aesthetically customised. It looks robotic rather than suited to the individual and does not fit with cultural expectations.
Community resilience	3D printers are 'parachuted in'. Community are not empowered to own the technology and develop their own solutions.
Preservation of socio-cultural patterns and practices	Design is developed mainly exogenously before arriving in South Sudan. It does not consider contextual needs.

Although the project was apparently motivated by the desire "*to make something that was sustainable for the community*" (11-01), there are some serious concerns about the credibility of this claim. To begin with, the project did not recognise the basic, contextual needs of the users.

The prosthesis design was mostly developed before Not Impossible arrived in South Sudan, and thus the users could not meaningfully participate in the design process. Indeed, the eponymous Daniel had no idea about the project until Not Impossible arrived to find him. He essentially became the subject of Not Impossible's 'othering', as they decided how best to help him and his community. The result was that the prosthesis was largely inappropriate and it did not fit with cultural expectations. After a while the community did not continue using the prostheses. According to an article in the Guardian, a doctor at the local clinic found that: "*as time went on none of the amputees were using the prostheses as they felt they were too cumbersome*" (Birrell, 2017).

Not only was the product unsuitable, but the project also failed to effectively establish a long-term plan for production, maintenance and repair. Some training was provided to the community. However, the community were largely technology illiterate and the training provided was very superficial. Clinical staff were also very overstretched and could not dedicate time to the project. Asides from the inadequate plan for local ownership, the maintenance of the printer and its supply of filament was completely overlooked. It soon became clear that the project was no longer viable after Not Impossible left South Sudan: "*Even though Mick trained the community member to use the 3D printers… after he left it became an issue with having the human capacity… the location of that clinic is in the Nuba mountains and they are actually still in conflict so the population is really transient. There isn't a lot of consistency of the employees [at the clinic] and the employees that they do have are just in really high demand for more emergency cases... So what we heard from the doctor that ran the clinic was that they just didn't have the bandwidth to dedicate to it.*" (11-01).

3.4.2 Arm prosthesis by 3D LifePrints

Whilst working in Kenya, Paul Fottheringham recognised the need for affordable and locally appropriate prostheses. He founded 3D LifePrints in 2013 after realising that 3D scanning and printing could provide a potential solution. 3D LifePrints spent three years based in Kenya developing the LifeArm, a customised upper arm prosthesis (see Figure 3.3). The organisation reports that the prosthesis was distributed free of charge to many healthcare providers in Africa, including Kenya and South Sudan. However, 3D LifePrints do not know how many beneficiaries have been fitted with prostheses or how many prostheses are still being used. Since 3D LifePrints left Kenya in 2016, the project has struggled and the organisation now focus on 3D printing applications in the Global North.

Table 3.5 illustrates how this project responds to the key themes of social sustainability. Whilst the project goes some way to addressing the themes of social sustainability, it is notably lacking in several key areas.

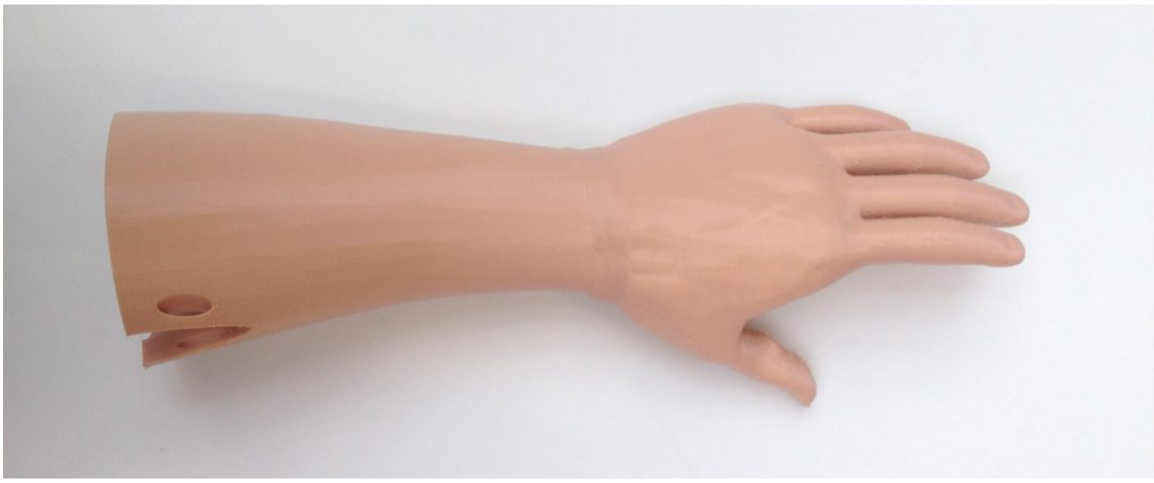

Figure 3.3 – LifeArm (3D LifePrints, n.d.)

Table 3.5 –Evaluation of arm prosthesis by 3D LifePrints

Themes of social sustainability	**How project addresses the key themes of social sustainability**
Basic needs and quality of life	Prosthesis is customised and humidity resistant to provide comfort to the end user. Number of prostheses distributed and actual impact is unknown.
Social justice and equity	Free prostheses for vulnerable populations in East Africa.
Employment	Local production of prostheses creates employment, however staff are mainly recruited from the Global North.
Decline of poverty	Potential for prosthesis to enable users to return to the workforce.
Education and training	3D LifePrints attempt to train engineering students and local prosthetists, however they report that there is limited interest.
Human dignity	Project aims to restore human dignity, however it does not challenge the dependency of vulnerable people.
Health and wellbeing	Initiative aims to fit within a system of care that also addresses trauma of amputees.
Participation	Some participation from users in the design process, however they mainly act as informants. Partnerships with international US and UK universities, and some local organisations, including healthcare providers and 3D printing social enterprises.
Sense of place and belonging	Prosthesis is designed to look as natural as possible and is available in 10 skin tones to promote users' sense of belonging.
Community resilience	Prosthesis is designed to be maintained locally, however community do not take ownership of the project. Prosthesis is developed using exogenous (human and infrastructural) resources. Initiative struggles to continue once organisation leaves East Africa. 3D LifePrints faced challenges getting buy-in for the project, because they were viewed as outsiders.

At its heart, the LifeArm project is based on the principles of social justice and equality. It seeks to provide affordable prostheses to vulnerable populations who are neglected by the current system. In comparison with the previous case study, the LifeArm was much more successful in addressing the basic and contextual needs of users. First, it was designed to be durable, anti-microbial, skin safe and humidity resistant. Second, it was designed to be as cosmetically attractive as possible to match cultural expectations and promote the users' sense of belonging in the community. Third, 3D LifePrints recognised the importance of fitting the prosthesis within a system of care to also address mental trauma: "*we saw it as a long-term solution, a person loses a limb for life and needs help for life*." (02-01).

So, what went wrong? Similar to the previous example, the project failed to establish itself as anything more than an outsider intervention. Even if the LifeArm was designed in Kenya, the project itself was still reliant on human and infrastructural resources from the North and it prioritised collaborations with US and UK universities over local partnerships. 3D LifePrints did attempt to train some engineering students and apprentices, however they ultimately felt that this was not a promising route as the students showed limited interest. The product itself was designed to be easily maintained using locally available materials, however an endogenous capacity was not established to do so. In the end, 3D LifePrints fell into the trap of the 'technology saviour' and the project's days were numbered after they left Kenya: "*we wanted to say look here's the technology, don't be scared of it, it's here to help your lives … unfortunately now I'm not there it's difficult to keep things moving and driving [forward]*." (02-01).

3.4.3 Suction pump spare part by Field Ready

Field Ready is an NGO whose philosophy is based on the local manufacture of humanitarian solutions. They first started experimenting with digital fabrication in 2014 as part of a pilot programme in Haiti. During this pilot programme, they produced several technical prototypes, including umbilical cord clamps and surgical tweezers. This trial programme technically validated the potential of digital fabrication in humanitarian/development settings. Subsequently, Field Ready established a programme in Nepal, using 3D printing to help with the recovery phase of the 2015 earthquake. Importantly, Field Ready recognised the potential for 3D printing to alleviate supply chain challenges, by creating solutions on demand at the point of need. When they first started working in Nepal, the 3D printing ecosystem was virtually non-existent in the country however the lead designer, Abigail Bush was able to contact a Nepali engineer, Ram

Chandra Thapa who had registered interest in 3D printing online. He joined Field Ready shortly after, and together Abigail Bush and Ram Chandra Tharpa worked to develop 3D printed solutions. Whilst working at Field Ready, Ram Chandra Thapa also set up Zener Technologies, a commercial 3D printing and prototyping company.

Figure 3.4 – Ram Chandra Thapa repairing a suction pump machine using 3D printing (Britton, 2018b)

With support from an international NGO, Field Ready was able to visit several health posts. An outcome from one such visit was the production of a 3D printed spare part for a suction pump machine (see Figure 3.4). Table 3.6 evaluates this project according to the themes of social sustainability.

The spare part was designed and manufactured by Ram Chandra Thapa at a rural health post in 2017, in response to seeing a broken connector on a suction pump machine. The replacement part was expensive and difficult for the health post to procure. Using 3D printing, a bespoke fix was provided within a matter of hours, restoring the function of a potentially life-saving device. On the surface, this project seems to be a success. However, a closer look raises some cause for concern. Although the part was validated on-site, its long term impact is unknown as no follow up was conducted by Field Ready. If the part breaks it cannot be maintained and repaired by the health post, who are located several hours away from Field Ready's office. The project effectively ended when the part finished printing and it does little to address the underlying health post's dependency on the broken aid model; rural health posts are isolated and are unable to procure the items they need. Whilst this project provides a quick-fix solution, it notably fails to consider the themes of social sustainability such as social capital, education, training and employment, that might have genuinely increased the health post's resilience to crisis.

Table 3.6 – Evaluation of suction pump spare part by Field Ready

Themes of social sustainability	**How project addresses the key themes of social sustainability**
Basic needs and quality of life	Restoration of a potentially life-saving device. Need fulfilment is validated on-site, providing clear proof of impact. Long term impact is unknown as there is no follow up.
Social justice and equity	Improving healthcare access in rural health post.
Social capital	Limited relationship building during one-off visit. Health post does not have a meaningful way of contacting Field Ready for ongoing support.
Employment	No new employment created.
Education and training	Demonstration of 3D printing on-site however no training is provided.
Participation	Direct engagement with clinical staff on-site.
Community resilience	On-site manufacturing provides an affordable solution that overcomes supply chain challenges. However, clinical staff are not empowered to maintain or repair the device if it breaks. Health post are reliant on Field Ready to provide any repairs to part. No follow up is provided so community resilience is limited.

3.4.4 Reconstruction housing model by Field Ready

Another project developed by Field Ready during a similar period also underlines the challenges associated with DF4D. Table 3.7 evaluates the social sustainability of a project to create a reconstruction housing model, using 3D printing and laser cutting. The project was initiated by another NGO who approached Field Ready to develop an accurate housing model to improve disaster preparedness in Nepal. They wanted a simple model that could demonstrate the required construction safety features to masons, who were not adequately trained on building for earthquake preparedness.

Although the project addresses some of the themes of social sustainability, such as education and training, safety and security, and the preservation of social patterns, it only partially addresses some of the other criteria. For example, the project aims to contribute to the community's resilience to earthquakes by supporting disaster preparedness. Yet, community resilience is ultimately limited by the fact the project is not initiated or driven by the local community. Again no employment is created locally, beyond the Field Ready team. The project notably fails to engage with local masons or construction workers. In this particular case, the project ended after a series of procurement challenges caused substantial delays, and meant failing to meet external deliverables. In this case, logistical factors are central to the project's failure. Yet, analysis of the project's contribution to the themes of social sustainability reveals other concerns about the project. Even if the project had not faced critical logistical challenges, it seems that social sustainability would have been significantly lacking.

Table 3.7 – Evaluation of reconstruction housing model by Field Ready

Themes of social sustainability	**How project addresses the key themes of social sustainability**
Employment	Employment created for Field Ready staff only.
Education and training	Models support practical training for local masons/construction workers on how to build housing for earthquake preparedness.
Community resilience	Project helps to support disaster preparedness, improving local resilience. However project is not initiated or driven by the local community.
Safety and security	Helping to rebuild safe housing for affected communities.
Participation	Local masons/construction workers are not involved in the development of models.
Preservation of socio-cultural patterns and practices	Models are compatible with local masonry techniques and available materials.

3.4.5 Improved cookstove by Field Ready

A third project by Field Ready shows the more promising potential of DF4D. Table 3.8 illustrates how the development of a cookstove air supply disk addresses the themes of social sustainability.

A Nepali entrepreneur, Mr Madhukar KC approached Field Ready in early 2016 for help manufacturing a new cookstove. In Nepal, 4.5 million households use wood fuel for daily cooking. However, these cookstoves have devastating health effects, which disproportionately impact women. Mr KC was already producing cookstoves and selling them on the local market, but as the burner efficiency rating was around 18% it was not high enough to be considered for government contracts. Mr KC was from a rural background himself, and recognised the problems with existing stoves. He had an idea to improve the efficiency of the air supply disk, however it was too complex to be machined in wood and he was unsure how to produce it.

Table 3.8 – Evaluation of improved cookstove by Field Ready

Themes of social sustainability	**How project addresses the key themes of social sustainability**
Basic needs and quality of life	20,000 affordable cookstoves have been installed across Nepal, which reduce harmful smoke emissions and fuel consumption.
Social justice and equity	Cookstove provides affordable access to people living in rural areas with low incomes. It specifically improves the lives of women who are disproportionately affected by health issues caused by cookstoves.
Employment	Local production of cookstoves creates employment. Women are employed as local installers to install the cookstoves in other people's homes.
Decline of poverty	Value creation in the local economy in Nepal. New revenue for Nepali entrepreneur (Mr KC), Zener Technologies (3D printing service company) and local sand-casting company. New income for local installers.
Education and training	Training for local installers and education about the health benefits of clean cookstoves for communities.
Health and wellbeing	Improved design has the potential for significant health and environmental benefits.
Participation	Mr KC is from a rural community and designed the improved cookstove based on his own experience using and manufacturing cookstoves. Women from rural communities participate in installation of cookstoves.
Safety and security	Old cookstoves were used outside whereas improved cookstove can be used safely inside the home.
Community resilience	Development of a local production ecosystem enables development of an endogenously designed and manufactured solution. 3D printing is still reliant on imported technology and materials and is subject to supply chain delays, limiting community resilience.
Preservation of socio-cultural patterns and practices	Cookstove supports cultural practice of cooking with wood fuel in rural areas. It is developed using endogenous skills.

Working closely with Mr KC, Field Ready were able to develop a CAD model of the air supply disk, and to 3D print a positive mould that could be used for sand-casting the final part. Mr KC was able to purchase the 3D printed moulds from Zener Technologies (the company that Ram Chandra Thapa, a Field Ready employee had set up). The improved cookstove had a new efficiency rating of 26%, which meant it offered a significant reduction in wood consumption and harmful smoke in the home. With this improvement, Mr KC was able to secure multiple government contracts to sell the cookstoves. In just six months he sold over 2000 cookstoves creating over $23,000 in revenue. Furthermore, he created significant employment for women in rural communities, who he trained as local installers (see Figure 3.5).

Whereas the previous two cases by Field Ready are focused on providing a specific solution, this project is brought about by an enabling ecosystem that Field Ready have helped to cultivate. By supporting local manufacturing capabilities, Field Ready advance social sustainability through the development of important solutions that would not have been initially planned for: *"Part of our role here isn't just to develop these solutions, but also to support the 3D printing sector, and the digital fabrication and manufacturing sector more broadly."* (06-03).

Figure 3.5 – A woman who has been trained to install the improved cookstoves (Britton, 2018a)

3.4.6 Tourniquets by Glia

Glia was founded by the Palestinian-Canadian doctor, Tarek Loubani. Whilst treating patients in Gaza he found that he was unable to access basic and life-saving medical devices. After struggling to procure the items he needed, he realised that local manufacture was the only viable option. To begin with, Tarek Loubani self-funded the development of a 3D printed open source stethoscope. The stethoscope was designed by researchers at University of Western Ontario with support from many volunteers who made contributions on GitHub, an open source repository. After testing it was found that the 3D printed stethoscope was comparable to standard models. The 3D printed version was also more than 95% cheaper, costing less than three dollars (Pavlosky et al., 2018).

Having proven the potential of 3D printing to create affordable and much-needed solutions, Glia installed 3D printers at their office in Gaza to begin manufacturing the device. In 2017, Gaza's disaster committee and the Hayat Center for Emergency and Crisis Management approached Glia's Gaza team in urgent need of a solution. They had been trying to obtain tourniquets, however had found them impossible to procure. Not only were they prohibitively priced at $50 per unit, but they were extremely difficult to obtain because of the blockade on imported items. Makeshift tourniquets were leading to unnecessary blood loss and fatalities. In response, Glia's Gaza team designed a low-cost tourniquet that could be easily 3D printed in five hours, and assembled with Velcro and nylon straps (see Figure 3.6). Their design was superior to the standard tourniquet because it was also suitable for paediatrics. Training on how to use the new tourniquet was provided to first aid responders. Since the beginning of 2018, one thousand tourniquets have been used to treat injured civilians.

Figure 3.6 – Tourniquets before packaging and ready for use (Loubani, 2018)

Table 3.9 illustrates how the tourniquet addresses the key themes of social sustainability. From the outset, the project was motivated by urgent medical needs and a deep concern for social justice. However, the project also considers several other themes of social sustainability. In order to facilitate the production of the tourniquets, Glia have been dedicated to developing a digital fabrication ecosystem in Gaza. Over twenty-five open source, locally manufactured 3D printers have now been installed across Gaza: "*we picked a model that was open source, it's the Prusa i3. That was important for a number of reasons, but one practical reason is that they are self-replicating... So once the first one showed up, then the rest were made by the first one.*" (05-01). All of the printers are solar powered and use locally produced filament, made from recycled plastic.

Not only has this distributed manufacturing network been vital to both scaling up production and mitigating against disruption, it has also created significant employment and increased community resilience. According to Glia, their work helps to revitalise a culture of manufacturing in Gaza. For example, 3D printers based at universities are made available for students to use as they wish, on the condition that they produce a certain number of tourniquets: *"If all we do is we give people a device and we say to them 'here's the device, go ahead and use it in only the way that we want' then we haven't really advanced the world around us."* (05-01). In doing so, people are empowered to start developing their own solutions. Central to the project is the belief that the tourniquet is just a means to an end. Ultimately, Glia seeks to challenge the model of dependency within the aid sector: *"A lot of people think that this is a technology project, or the open-minded among them think of this as a health project. It's neither. It's a liberation project. This project is about freeing people."* (05-01).

Table 3.9 – Evaluation of tourniquets by Glia

Themes of social sustainability	**How project addresses the key themes of social sustainability**
Basic needs and quality of life	Deployment of 1000 life-saving devices to control bleeding wounds.
Social justice and equity	Provides an affordable device to treat a marginalised population. Over twenty-five 3D printers are made accessible to the community in Gaza.
Employment	Three people are employed by Glia in Gaza to design and manufacture the tourniquet. A new production economy is created in Gaza through the recycling of plastic and local filament production.
Decline of poverty	New livelihoods for local suppliers, designers and manufacturers.
Education and training	Training for 25 first responders on how to use the tourniquet. Some 3D printing training is provided to the community, the community relies on champions to voluntarily train others.
Participation	Community in Gaza are responsible for driving the design of the tourniquet. Clinical staff provide necessary expertise. Community are empowered to design and manufacture their own solutions.
Sense of place and belonging	Creating a maker culture in Gaza and building pride in community identity.

Safety and security	Community are empowered to handle their own safety/security.
Community resilience	3D printers are distributed across Gaza to mitigate against disruption and quickly scale up production. People are empowered to develop local solutions to overcome supply chain disruption. Remote support is provided by Glia employees in Canada and Slovenia.

3.4.7 Handwashing device by Oxfam

Oxfam are an international NGO whose work is focused on poverty eradication and disaster relief. In 2014 they launched a project using 3D printing to help deliver water, sanitation and hygiene (WASH) kits. They partnered with iMakr, a 3D printing services company in the UK to deploy a 3D printer in their Syria crisis response in Lebanon. With iMakr, Oxfam launched an online design website on the MyMiniFactory platform to crowdsource designs for 3D printing a water-saving hand washing device. Handwashing is a vital means of preventing diarrhoeal disease and maintaining good health in emergencies. However water is often scare in disaster zones, and so providing a water-saving device is valuable for preserving resources. The project aimed to 'bootstrap' the design process by crowdsourcing designs, however contributors were inexperienced and had little understanding about the use-context. As a result Oxfam found that the quality of designs they received were inadequate: *"some of the solutions we received were pretty out there and different [haha]… I don't think any of the ideas were particularly printable in the end"* (12-01).

Furthermore, the organisation struggled to identify a suitable capacity to take ownership of the project. Instead of creating new employment, the project just increased the existing work load of the aid workers in the field, who were already overstretched: *"it takes a lot of time to do 3D printing, so they [aid worker] weren't necessarily doing their day job because they were spending so much time doing 3D printing"* (12-01). More broadly, the project took a technology-driven approach that failed to meaningfully engage with users. Their participation, and ultimately their real needs, were completely overlooked: *"It just felt like bringing a solution without a problem. We were trying to find the problem to be solved but we couldn't find it."* (12-01).

Figure 3.7 shows some of the ideas that were developed and tested in the project and Table 3.10 illustrates how the project addresses the key themes of social sustainability.

Figure 3.7 – Handwashing device design and testing (Gardner, 2014)

Table 3.10 – Evaluation of handwashing device by Oxfam

Themes of social sustainability	How project addresses the key themes of social sustainability
Social justice and equity	Project aims to provide sanitation to marginalised community living in refugee camps in Lebanon.
Health and wellbeing	Project aims to reduce spread of diarrhoeal disease.
Employment	No new jobs created. Production of handwashing device is an additional responsibility for Oxfam employees. Relies on a network of volunteers to create designs.
Education	Education around handwashing is not considered.
Participation	No participation from users. Crowdsourcing is used to leverage volunteer design network.
Sense of place and belonging	The design is crowdsourced from contributors who have no knowledge of the context of use.
Community resilience	Local manufacturing aims to reduce supply chain challenges. However, design is driven completely exogenously and community are not empowered to own the solution. Little consideration is given to the supply chain for maintaining and repairing the handwashing device and the 3D printer itself.

3.4.8 Medical spares by 3D4MD and Médecins San Frontières

3D4MD is a social enterprise based in Canada focused on 3D printing and healthcare. Médecins San Frontières (MSF) is an international NGO focused on healthcare in humanitarian crises. In late 2017, 3D4MD and MSF set out to work on a project to 3D print temporary spare parts in the field. The proposal put forward a collaboration in which MSF logisticians would be trained to operate 3D printers in the field, and 3D4MD would provide designs that had been crowdsourced from the Medical Makers' network. The project ended after the initial research phase, as a contract could not be agreed between the parties. Table 3.11 shows how the project addresses the themes of social sustainability. In many ways, the project replicates a similar approach to the previous example by Oxfam.

Table 3.11 – Evaluation of medical spares by 3D4MD and MSF

Themes of social sustainability	How project addresses the key themes of social sustainability
Basic needs and quality of life	Project aims to provide short-term spare parts to remote areas where supply chains are disrupted.
Employment	New employment for 3D4MD. Additional responsibility for MSF staff.
Education and training	Limited training on how to use 3D printers provided to MSF staff. They are not well equipped to deal with the technological challenges.
Participation	Crowdsourcing designs from Medical Makers' network. No wider involvement of the community.
Sense of place and belonging	Designs are to be created exogenously by designers with no experience of context of use.
Community resilience	3D printers and materials are to be parachuted in. Local community are not empowered to own the technology and develop their own solutions.

3.4.9 Medical shoe by AB3D

AB3D or African Born 3D Printing was founded in 2012 in Kenya by two graduates from University of Nairobi. Initially they worked on prototyping a custom medical shoe which they called 'Happy Feet'. They aimed to provide comfortable footwear for people suffering from jiggers infestation, a common skin disease among low socio-economic groups in East Africa that causes foot deformity. AB3D found it challenging to develop the product beyond the initial prototype as there was limited interest from affected groups. However, whilst developing the project, they also realised that imported 3D printers were not robust enough to handle the fluctuations in voltage, humidity and dusty environment. Furthermore, attempting to repair the machines was almost impossible because of challenges procuring spare parts and finding certified engineers to repair them. As a result, the focus of the organisation shifted to locally producing affordable 3D printers specifically designed for use in Kenya. Table 3.12 illustrates how the project addresses the themes of social sustainability.

Table 3.12 – Evaluation of medical shoe by AB3D

Themes of social sustainability	How project addresses the key themes of social sustainability
Basic needs and quality of life	Development of a customised medical shoe for people suffering from jiggers infestation in Kenya.
Social justice and equity	Aims to help poor who are often stigmatised because of foot deformities.
Participation	Some engagement with local shoe makers, but they are reluctant to engage with the project. Little engagement with people suffering from jiggers infestation. There is little local buy-in.
Sense of place and belonging	Aims to restore confidence and allow people to interact in the community without stigma.
Community resilience	Development of a local 3D printing ecosystem. Locally produced 3D printers using e-waste to increase supply chain resilience.

3.5 Reflections on the findings

Although literature on DF4D is relatively sparse it has tended to focus on positive narratives. Rhetoric about DF4D claims that it will radically transform the supply of products in the aid sector (Birtchnell & Hoyle, 2014; James, 2017; Loy et al., 2016). It is generally predicted that DF4D will increase local ownership and community resilience by promoting more localised forms of production (Corsini, Aranda-Jan, & Moultrie, 2019). This chapter has provided a more critical account to contest these claims. It has shown that whilst the themes of social sustainability are visible in some projects, social sustainability as a whole is significantly lacking. The findings reveal a notable chasm between the rhetoric and reality of DF4D.

Whilst the literature often reports on DF4D as an unequivocal success, this study has revealed a darker side of DF4D. The majority of cases reviewed were found to be total or partial failures. Several projects have been abandoned before implementation. There also seems to be little transparency in reporting on DF4D. Many projects are still promoted as success stories, even when they have failed. It was also found that whilst DF4D is often painted as a new model that can advance 'local solutions by local people', many projects still reinforce models of dependency and can be considered as 'outsider interventions'. There is concern that DF4D projects are often being masqueraded as emancipatory endeavours when in reality, they do not significantly advance the social sustainability of the communities they claim to serve.

Broadly speaking, DF4D projects tend to focus on the issues of basic needs, health, social justice and equity. However, the other themes of social sustainability such as participation, employment, education, community resilience and preservation of social-cultural patterns are neglected. The findings also suggest that the latter set of factors are broadly interconnected. For example, in Project Daniel the community had very limited ability to participate and express their own needs. As a result the final outcome neglected to consider the socio-cultural practices of the community. Furthermore the failure to address the themes of education and employment, meant that the underlying lack of community resilience was overlooked. In contrast, when participation is meaningful it seems to have a positive uplift on other dimensions of social sustainability. In the example of Glia, the inclusion of the wider community in the design and manufacture of the tourniquet helped to establish a maker culture in Gaza that positively reinforced peer to peer learning. Thus, participation opens the door for education and community resilience.

The study also drew attention to the dominance of technology-driven approaches in DF4D projects. Organisations present themselves as technology saviours and projects seek quick fixes without considering the human and social resources that are required to make them work in the long term. Among the failed initiatives, technology was often the initial project trigger. For example, Field Ready sent 3D printers to a rural health posts looking for things to print; Oxfam searched for products in their catalogue that they thought could be 3D printed; 3D4MD sought to deploy 3D printers to remote locations in East Africa in the belief that 3D printing could be valuable. In contrast, in the successful initiatives that broadly addressed social sustainability, projects were requested by the local communities themselves. When Mr KC approached Field Ready for help with an improved cookstove, and when Gaza's disaster team approached Glia, they did not have a technology in mind per se. Of course, neither of these projects could have been possible without digital fabrication, and the development of an endogenous capacity. These findings reinforce the argument that "*technology—no matter how well designed—is only a magnifier of human intent and capacity. It is not a substitute*" (Toyama, 2010). It also suggests that a holistic view of the social sustainability might help to mitigate against technology-centred thinking.

Overall, the themes of social sustainability have been useful in evaluating the projects. The findings show that when there is a narrow focus on the themes, projects tend to be total or partial failures. Conversely, when the themes of social sustainability are broadly addressed, projects are more likely to be successful. This is not to say that the absence of social sustainability is the sole cause of project failure, it is rather that social sustainability appears to be a key contributor to project success. This study therefore suggests that social sustainability is indeed an important factor in DF4D projects, and that by and large social sustainability is not being adequately or consistently addressed. This study also makes clear that there are inadequate solutions to address this problem. If design is the means by which social sustainability is manifested in DF4D projects, then clearly DfSS is lacking. Although the themes of social sustainability are helpful in evaluating the projects ex post facto, they fall short of providing a practical means to advance social sustainability during the stages of product development. The absence of practical design tools and methods is clearly a limiting factor in DF4D:

> "*Sometimes I'm unsure what to focus on when I'm designing. When you're working on a spare part for a power unit in a hospital, you can see what it does in the short-term. It's harder to understand it's long term impact… there is a tension between problems that you can solve straight away because they are easy and problems that take a lot longer to solve but might have more benefits… So are we doing the right thing in the long run, I'm really not sure if we really get this right."* (07-02).

This comment effectively reflects on the challenges of assessing which projects are more or less socially sustainable. Although the potential for design to advance social sustainability is implicitly recognised by designers in DF4D projects, this study made apparent that there is a scarcity of tools available to them. Practically speaking, this meant that designers lacked suitable guiding principles or evaluation criteria to support the development of socially sustainable projects.

3.6 Summary

This chapter has reflected on the concern that social sustainability is lacking in DF4D. To begin with, social sustainability was introduced as an important but nebulous concept that has traditionally been overlooked in integrated sustainability approaches. The chapter presented some of the various definitions and principles of social sustainability, also revealing some more recent attempts to operationalise the concept. Given the limited existing research on DF4D, empirical evidence was collected about fourteen real-world projects. The projects were evaluated using the key themes of social sustainability found in the literature. Contrary to mainstream narratives, the analysis revealed that many projects are total or partial failures. It was shown that social sustainability is not being sufficiently addressed in the majority of DF4D projects, which is limiting their success. Moreover designers are not adequately equipped to remedy this. DfSS is clearly lacking and there is a paucity of practical tools to support DfSS. To return to the original question at the outset of this chapter, social sustainability is indeed missing in DF4D, and the role of design in promoting social sustainability is not substantially developed. This study argues that this is negatively impacting the success of projects. The next chapter will begin to address this problem by reviewing the literature to establish a conceptual foundation of DfSS that will help to frame the subsequent research.

Chapter 4 What is already known about Design for Social Sustainability?

4.1 Introduction

In the previous chapter it was confirmed that on the whole social sustainability is lacking in DF4D projects. Given that design is an important means by which social sustainability is manifested in DF4D projects, it was argued that DfSS is also lacking. The study also showed that there are scarce resources available to support DfSS, and that this is a limiting factor for DF4D projects at present. This chapter aims to address this problem, by developing a conceptual understanding of DfSS. Section 4.2 will help to position design in relation to research on social sustainability. Sections 4.3 and 4.4 will explain the methods used to collect and analyse literature on DfSS, as part of an extended literature review. Section 4.5 will summarise the existing knowledge on DfSS. It will present the terminology, methods, focus and topics covered in the literature, and discuss the key themes and findings. Section 4.6 will reflect on the literature, to conceptually develop DfSS. Finally Section 4.7 will summarise the main contributions of this chapter and set out the implications for the next stages of the thesis.

Parts of this chapter have been published in Corsini & Moultrie (2019).

4.2 The role of design

This thesis considers social sustainability as the preservation of the social system in which people are not subject to structural obstacles. In other words, social sustainability is concerned with the wellbeing and flourishing of societies now and in the future. To date, most attempts to practically address social sustainability have focused on the development of social indicators or social impact assessment tools (Colantonio, 2009; Wu et al., 2014). Instead, this thesis seeks to investigate design as a key strategic lever for promoting social sustainability in DF4D. Specifically, it aims to develop a conceptual and practical understanding of Design for Social Sustainability (DfSS). This research takes the view that design is a catalyst for change, considering that:

> "*design is an act of deliberately moving from an existing situation to a preferred one by professional designers or others applying design knowingly or unknowingly*" (Fuad-Luke, 2009, p. 5).

Although research on social sustainability is now flourishing, the role of design is rarely discussed. The exception is within the field of urban design, where it seems that the design of physical spaces makes the 'social' more obvious than in the design of products. Still this work remains isolated from other domains. Furthermore it tends to be practice-oriented and does not contribute to the conceptual development of DfSS. For example, The Young Foundation produced a report on DfSS which defines important elements for building new communities and urban spaces (Woodcraft, 2012). A report by the Environment Design Guide also documents how an inclusive design process helped to facilitate more socially sustainable infrastructure and local services (Palich & Edmonds, 2013). Other authors consider social sustainability as an outcome of urban design, but do not specifically examine the role of design in promoting social sustainability (Bramley et al., 2009; Chan & Lee, 2007).

Despite the fact that the role of design is not well established in the social sustainability literature, a look at history reveals that design has always played an important role in the preservation of social systems. In 1893, William Morris published the Ideal Book calling on designers to reject the poor social conditions and quality of goods resulting from Industrial Revolution. As widespread industrialisation took hold in 20th century, several design practitioners including Buckminster Fuller, Victor Papanek and Nigel Whitely also advocated for a more socially orientated design practice. Their calls for design to address *"the real issues and concerns, rather than the phoney desires dreamt up by capitalist manufactures and their 'lackeys'… industrial designers*" (Whitely, 1993, p. 95), were manifested in the development of design approaches such as socially useful design, socially responsible design and social design.

More recently, design theorists such as Ezio Manzini and Tony Fry have set out the role of designer as an activist who can initiate change. In *Politics of the Everyday*, (Manzini, 2019) builds on his previous work *Design, When Everybody Designs* to argue that design is a political tool, in that it constructs visions of how the world should be. Manzini advocates a capability approach that echoes Amartya Sen's earlier work on development economics (Sen, 1991, 2002). Manzini reflects on the emergence of the 'diffuse designer', in which non-expert designers are active in shaping the world around them through everyday practice. In contrast to the widespread "Diffusion of Innovations" theory by Rogers (1983) Manzini calls for the diffusion of capabilities, which enable communities to develop solutions for their own needs. Similarly, in *Design as Politics*, (Fry, 2011) argues that design is not neutral but that its potential for making firmly establishes itself as a political practice that shapes the world. Fry argues that design therefore has a moral obligation to 'sustainment', an alternative to sustainability which calls for "*economic and socio-cultural reconstruction that… transcend[s] the ways 'we' destroy our worlds and each other*".

4.3 Searching for existing knowledge on Design for Social Sustainability

In the previous chapter it was shown that social sustainability is a key gap in DF4D. There is clear reason to believe that design can promote social sustainability, however as already discussed the role of design has been largely overlooked in mainstream research on social sustainability. In order to help conceptualise DfSS, it was therefore decided to turn to the design literature and to search for relevant works, as part of an extended literature review. Figure 4.1 shows how the literature in this chapter is related to the literature on social sustainability discussed in Chapter 3. It also shows how Design for Social Sustainability focuses on scholarship at the intersection of social design and sustainable design.

To examine existing knowledge on DfSS, a number of initial search terms were identified related to design, social sustainability, and similar terms. Literature was gathered using Scopus and Google Scholar, with the following searches: "social sustainability" AND "design"; "design for social sustainability"; "socially sustainable design"; "design for social impact"; "design for sustainable social impact"; "design for sustainable social change". As this resulted in only a small number of articles, it was also decided to expand the literature to include search terms from the domains of social design and sustainable design, including: "socially useful design"; "socially responsible design"; "sustainable product design". The aim of these searches was to look for literature at the intersection of these domains that considered design and social sustainability (see Figure 4.1). All articles were examined up until 2019 (March). When using Google Scholar, the first two pages for each search were retrieved for screening. This resulted in a total of 744 articles for review.

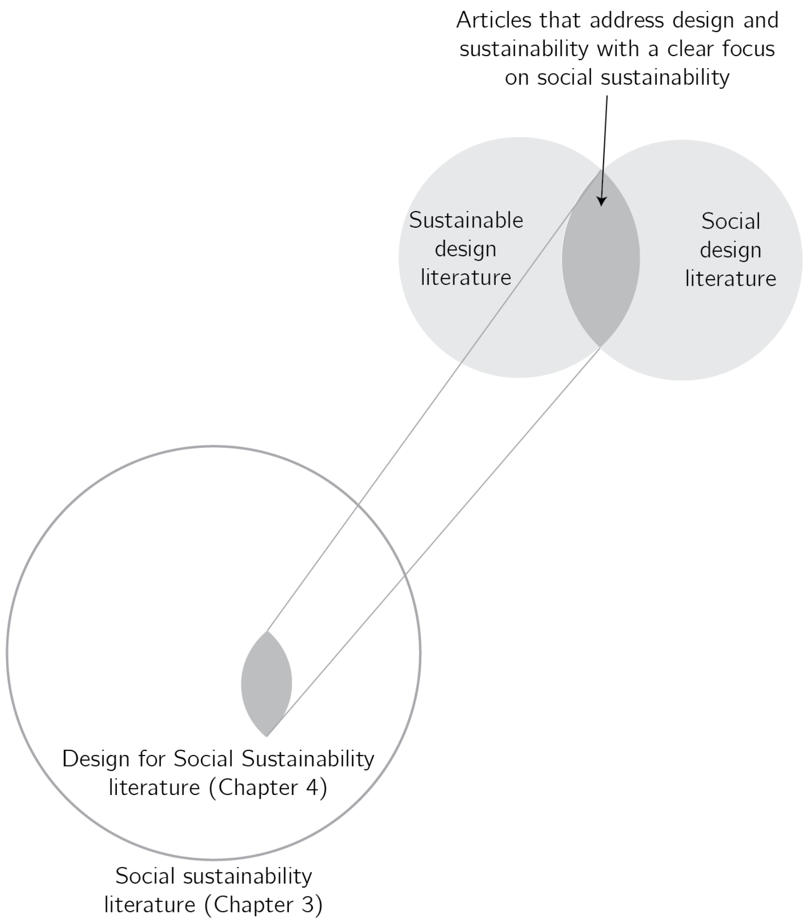

Figure 4.1 – Searching for literature on Design for Social Sustainability

An inclusion/exclusion criteria was established to support the review process (see Table 4.1). For practical reasons, only peer-reviewed journals in English were included. Books, book chapters, conference papers and reports were therefore initially excluded. The second criteria determined that articles must address sustainable design with a clear focus on social sustainability. For example, articles that only mentioned social factors superficially, with a major focus on environmental factors were therefore excluded. Third, it was decided to only include articles that were related to product design. This meant that any articles on urban design, supply chain or general management and strategy were excluded to begin with.

An initial review of titles and, if necessary, abstracts was used to determine relevant papers. This resulted in the exclusion of 674 articles (34 were duplicates, 49 were not peer reviewed and 591 were irrelevant). This left 72 articles for full paper review. At full paper review, 17 papers were removed as 11 papers were not relevant to social sustainability, and 6 papers were not relevant to product design. This resulted in a total of 55 papers that met the criteria identified. A further 9 papers were included using snowballing, resulting in a total of 64 papers. Upon reviewing the papers, a decision was made to include two papers related to urban design despite the initial inclusion/exclusion criteria. These papers were highly cited and cited among other papers that met the criteria. Furthermore, one book chapter by Bhamra et al. (2013) was included as the author's other papers were separately identified as key contributions. See Figure 4.2 for an overview of this review process.

Table 4.1 – Initial inclusion and exclusion criteria for the systematic literature review

Inclusion criteria	**Exclusion criteria**
1. Peer-reviewed journal in English.	Books, book chapters, conference papers, reports.
2. Articles that address sustainable design, with a clear focus on social sustainability.	A lack of focus on social sustainability and design, and instead a focus on environmental sustainability.
3. Articles that are related to product design.	Articles related to urban design, supply chain, general management and strategy.

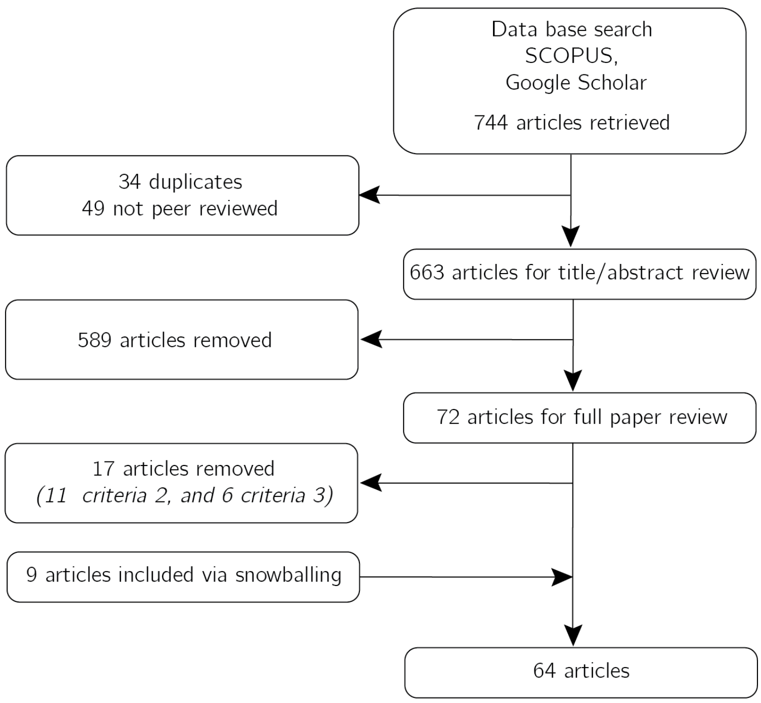

Figure 4.2 – Systematic literature review search process

4.4 Analysing the literature

To begin with, each of the articles was carefully read and analysed with respects to the: main findings; terminology used (e.g., socially responsible design, design for sustainable development etc.); main focus (e.g., design education, design theory, design methods, metrics etc.); topics covered (e.g., participatory design, codesign, systems thinking, behavioural change etc.); methodology (e.g., case study, action research, interviews etc.); and, research context (e.g. Global North, Global South, industrialised, community-scale). This detailed analysis guided interpretation of the literature and the key themes of DfSS were documented for each article.

Thematic analysis was selected to investigate the key themes of DfSS found within the literature. Thematic analysis is concerned with finding explicit ("semantic") and implicit ("latent") themes within data (Braun & Clarke, 2006; Gibbs, 2007). It is a useful approach for interpreting data in order to provide detailed accounts (Gebru et al., 2019). An initial analysis of the literature resulted in 46 themes. The key themes of DfSS were then analysed using a systematic process of defining categories and identifying the relationships between those categories in order to group conceptually similar themes (Gibbs, 2007). This resulted in 36 sub-themes, which were further grouped into 15 themes. For example, the sub-themes 'democratic/participatory', 'collaborative', 'cooperative', 'bottom up', and 'relational/people focused' described the participation of different actors in the design process and therefore formed the higher level theme 'participatory'. Similarly, 'culturally sensitive design', 'situated design', 'appropriate technology' and 'local suitability' were concerned with design that is appropriate for the context and these themes were grouped together to form the key theme 'contextual'. This created a working list of DfSS themes, which inform later stages of the research.

Table 4.2 – Overview of terminology used in the literature

Terminology	Main focus	Papers	Example definition
Socially useful design	The design of useful products that are accessible and affordable to everyone. Design that resists market forces.	Cooley, 1986	"Socially useful design not merely exposes this process [existing production/consumption patterns] but also presents constructive alternatives." Cooley (1986)
Sustainable design, sustainable product design, sustainable product development, design for sustainability.	The design of products that minimise negative impacts on the environment, whilst creating economic and social benefits.	Margolin, 1998; Manzini & Vezzoli, 2003; Maxwell & van der Vorst, 2003; Dewulf, 2003; Lilley et al., 2005; Howarth & Hadfield, 2006; Thomas, 2006; Waage, 2007; Clark et al., 2009; Lilley, 2009; Melles et al., 2011; Morelli, 2007; Bhamra et al., 2013; Bhamra et al., 2013; Gmelin & Seuring, 2014; Ceschin & Gaziulusoy, 2016; Haug, 2017	"Design for sustainability is design with the intention to achieve sustainable outputs. It is design that considers the environmental and social impacts of a product, service or system at the same level that economic concerns are considered" (Bhamra et al. 2013)
Sustainable product service systems (S. PSS)	The design of product-service systems where the economic interest of the providers continuously creates environmentally and social-ethically solutions.	Manzini and Vezzoli, 2003; Vezzoli et al., 2015	"An offer model providing an integrated mix of products and services that ... continuously seeks environmentally and socio-ethically beneficial new solutions" (Vezzoli et al., 2015).
Social design, design for social impact	The design of products that seek to bring about positive social change. Tends to focus on design in small projects or communities.	Margolin & Margolin, 2002; Stairs, 2005; Amatullo et al., 2010; Sklar & Madsen, 2010;Chen et al., 2016; Kang, 2016; Koskinen & Hush, 2016; Lie, 2016; Tromp & Hekkert, 2016; Yee & White, 2016	"Social design and social designers might be used to reconfigure and create better social-cultural technical relations, thereby constructing sustainable social infrastructures grounded in local participation and indigenous knowledge." (Kang, 2016)
Design for sustainable behaviour	The design of products that make people adopt desired sustainable behaviour and stop unwanted sustainable behaviour.	Lilley et al., 2005; Lilley, 2009; Lilley & Wilson, 2013	"To reduce use impacts by purposefully shaping behaviour towards more sustainable practices" (Lilley, 2009)

Socially responsible design, design responsibility	The design of product-systems that address global social, environmental and economic issues. Often related to Design for Bottom of the Pyramid (BoP), Design in Global South, Design for Development or Humanitarian Design.	Bezerra & Brasell-Jones (2005); Cooper, 2005; Gamman & Thorpe, 2006; Er & Kaya, 2008; De Vere et al., 2009; Caruso & Frankel, 2010; Hanusch & Birkhofer, 2010; Schaber, 2010; De Vere et al., 2011; Melles et al., 2011; Ramirez, 2011; Cipolla & Bartholo, 2014; Melles et al., 2015; Koo, 2016; Koo & Cooper, 2016; Lie, 2016; Rose, 2016; Bennett & Cassim, 2017	"Socially responsible design refers to design within the realm of social need, and upheld by a definition where it is "grounded in human dignity and human rights" (Caruso & Frankel, 2010) "Socially responsible design is a system perspective approach by which design decisions can incorporate the three dimensions of financial, environmental, and social issues" (Koo & Cooper, 2016)
Socially responsive design	The design of product-systems which address social, environmental and economic issues, and sits within the marketplace.	Gamman & Thorpe, 2006; Thorpe & Gamman, 2011	"[Its] potential for generating "innovation' in terms of the marketplace, may mean it does not simply equate with some purist definitions of socially responsible design... Socially responsive design tends to start with designers individually, or as a group, trying to make their intervention through practice" (Gamman & Thorpe, 2006)
Design for social innovation, socially innovative design	Design processes that develop and scale up social innovations. Emphasis on the role that people and communities can play in driving local change.	Morelli, 2007; Hillgren et al., 2011; Manzini, 2011; Björgvinsson et al., 2012; Chick, 2012; Manzini, 2013; Cipolla & Bartholo, 2014; Manzini, 2015	"[Design for] Social innovation is a process of change emerging from the creative re-combination of existing assets (from social capital to historical heritage, from traditional craftsmanship to accessible advanced technology), the aim of which is to achieve socially recognized goals in a new way" (Manzini, 2013)
Social sustainability in design, socially sustainable design, socially sustainable products, design for socio-ethical sustainability	The design of products that seek social sustainability. Incorporating social sustainability into design processes and practices.	Vezzoli, 2006; Birkhofer, 2010; McMahon & Bhamra, 2011; Asheim et al., 2012; Chick, 2012; McMahon & Bhamra, 2015; Woodcraft, 2015; Calvo & De Rosa, 2017; Gould et al., 2017; Mendoza et al., 2019	"Social sustainability in design, therefore calls for a deep understanding of human behaviour, fulfilling human needs and wants whilst being cognisant of (amongst other things) environmental limits, product responsibility, resource use and carrying capacities. As well as paying due attention to history; traditions; engaging in dialogue; having equity in expressing ideas; compromise; self-fulfilment and altruism in design practice are fundamentals in working towards social sustainability." (McMahon & Bhamra, 2011) "Socially sustainable product development is the processes and practices that lead to products whose lifecycles have a less negative impact on the social system." (Gould et al., 2017)
Design for sustainable social change	Design of products-systems that can sustain (positive) social change.	R. C. Smith & Iversen, 2018	"Creating multiple opportunities for sustaining and scaling projects, beyond the agency of individual actors, within larger communities and across domains and stakeholders at various levels of authority." (R. C. Smith & Iversen, 2018)

4.5 Summary of existing knowledge on Design for Social Sustainability

4.5.1 Terminology

It was found that a wide range of terms were used inconsistently throughout articles to refer to the same phenomena. Of the sixty-four articles that met the criteria, ten specifically use the terms "social sustainability in design", "socially sustainable design", "socially sustainable products", "design for socio-ethical sustainability" or "design for social sustainability". However different terms were often used throughout the articles. For example, multiple articles used the term "socially sustainable products" interchangeably with "socially responsible design" or "design for social innovation"; and "design for social innovation" was used interchangeably with "social sustainability" and "sustainable development". These findings reflect a lack of precision in the literature and highlights that existing knowledge is disparate and fragmented between different approaches. Table 4.2 provides a summary of the related terminology to DfSS found in the literature and offers some exemplary definitions of these related terms. This table is roughly organised in chronological order to reveal the evolution of different approaches in the field.

Among the ten articles that explicitly use the terms "design for social sustainability" or "socially sustainable design", precise definitions are notably lacking. For example, Chick (2012) refers to social sustainability, however uses this term synonymously with sustainable development, social impact and design for social innovation. Elsewhere R.C. Smith & Iversen (2018) explicitly focus on how participatory design can bring about sustainable social change. Their understanding of "design for sustainable social change" recognises the need to scale impact and points towards the importance of project-based thinking. Within the literature, the most detailed definition is provided by McMahon & Bhamra (2011) who examine how social sustainability might be integrated into design education. They explain that social sustainability in design:

> "*calls for a deep understanding of human behaviour, fulfilling human needs and wants whilst being cognisant of (amongst other things) environmental limits, product responsibility, resource use and carrying capacities. As well as paying due attention to history; traditions; engaging in dialogue; having equity in expressing ideas; compromise; self-fulfilment and altruism in design practice are fundamentals in working towards social sustainability*."

This definition makes clear that DfSS must respond to human needs, and that in order to do so DfSS must consider a broader set of socio-cultural themes such as tradition, equity, and self-fulfilment. This definition provides a useful starting point, and it refers to several of the key themes of social sustainability identified in the previous chapter. However it is worth noting that the emphasis of McMahon and Bhamra's (2011) work is mainly on the cultivation of responsible and ethical design practices, what they call social sustainability *in* design. This thesis goes further to consider DfSS as both social sustainability *in* design and social sustainability *by* design. In other words, it seeks out socially sustainable design practices, and also positions design as a means by which social sustainability might be achieved.

For absolute clarity it is worth repeating that this thesis considers social sustainability to be the preservation of the social system, in which people are not subject to structural obstacles (i.e. barriers that are systemically rooted in social institutions). Put another way, social sustainability is concerned with the human wellbeing and flourishing of societies now and in the future. This thesis therefore considers DfSS to be the combination of design processes and practices that advances social sustainability. DfSS entails design that that leads to the preservation of social systems and the removal of fundamental obstacles that destroy these systems. DfSS is design that supports human wellbeing and flourishing now and in the future.

4.5.2 Methods, focus and topics covered

The analysis also revealed that the majority of articles are case studies (23 papers), conceptual papers (20 papers), or review papers (10 papers). Only a handful of papers used design experiments or tests (5 papers), action research (3 papers), surveys (2 papers) or design ethnography (1 paper). These findings are consistent with the reality that many papers are still exploring and clarifying the role of design with respects to social sustainability. In terms of the research context, it was found that the majority of papers are focused on community/small-scale projects (23 papers) as opposed to industrialised projects (6 papers), with 34 not specifying the context at all. It is perhaps not surprising that DfSS seems well suited to community-based projects, in which social relations play an important role in the design process. Roughly even proportions of papers focused on projects in the Global North and Global South, however, many of the papers emphasised the relevance of DfSS in designing for marginalised people. For example, Lie (2016) states: *"designers connected to this movement generally focused on* *disadvantaged sectors of society, using alternative and appropriate technology and encouraging an efficient use of resources."*

Further analysis of the key focus of the papers and topics covered is shown in Table 4.3. It was found that the majority of papers (25 papers) focus on developing new methods and practices. Another group of papers (20 papers) focus on advancing design theory, by suggesting new ways of doing or thinking about things. A small number of papers focus on how to teach social design approaches (6 papers), and how to measure its impact (6 papers). Only three papers focus on DfSS related principles or definitions, and one paper provides a detailed design history. In terms of the topics covered, a common set of subject-matters emerged across the papers. In particular, participatory design, co-design, human-centred design, collaboration, democracy, distributed design, local design and networks emerged as some of the most frequently mentioned topics.

Table 4.3 – Focus and topics covered in the papers reviewed

Focus	**Topics covered**	**Papers**	**#**
Methods and practices	Participatory design, co-design, systems, collaboration, relationships, social work, agency, holistic design, networks, production paradigms, late-comer industrialisation, product sustainability, process sustainability, product innovation, product-service systems, spacio-social systems, socio-technical systems, prototyping, tacit knowledge, behaviour change, user behaviour, design culture, design competencies, triple bottom line, life-cycle analysis, capacity building, change management.	Amatullo et al., 2010; Bennett & Cassim, 2017; Caruso & Frankel, 2010; Ceschin & Gaziulusoy, 2016; Chick, 2012; Clark et al., 2009; Cooper, 2005; De Vere et al., 2011; Er & Kaya, 2008; García, 2015; Gmelin & Seuring, 2014; Hanusch & Birkhofer, 2010; Kang, 2016; Lilley, 2009; Lilley et al., 2005; Lilley & Wilson, 2013; Margolin & Margolin, 2002; McMahon & Bhamra, 2011; Morelli, 2007, 2012; Rose, 2016; Sklar & Madsen, 2010; R.C. Smith & Iversen, 2018; Thomas, 2006; Thorpe & Gamman, 2011; Tromp & Hekkert, 2016; Waage, 2007; Yee & White, 2015	28
Design theory	Participatory design, co-design, human-centred design, democracy, expert design, design thinking, systems, product-service systems, distributed design, localisation, networks, socio-technical systems, prototyping, infrastructuring, market-led design, design against crime, universal design, strategic design, resilience, decision making.	Bezerra & Brasell-Jones, 2005; Bjögvinsson et al., 2012; Calvo & De Rosa, 2017; Chen et al., 2016; Cooley, 1986; Gamman & Thorpe, 2006; Hillgren et al., 2011; Kadir & Jamaludin, 2013; Koo, 2016; Koo & Cooper, 2016; Koskinen & Hush, 2016; Manzini, 2011, 2013, 2015a; Manzini & Vezzoli, 2003; Margolin, 1998; Morelli, 2012; Stairs, 2005; Vezzoli, 2006; Vezzoli et al., 2015	20
Design education	Participatory design, human-centred design, empathy, culture, designer competencies.	Asheim et al., 2012; De Vere et al., 2009, 2011; Kadir & Jamaludin, 2013; Melles et al., 2015; Ramirez, 2011; Schaber, 2010	7

Measures	Impact assessment, social sustainability indicators, product life-cycle.	Dewulf, 2003; Gould et al., 2017; Howarth & Hadfield, 2006; Maxwell & van der Vorst, 2003; Mendoza et al., 2019; Woodcraft, 2015	6
Principles	Empathy, dialogue, ethics, inclusion, education, reflection, engagement, flexibility.	Cipolla & Bartholo, 2014; Haug, 2017; McMahon & Bhamra, 2015	3
Design history	Participatory design, co-design, Scandinavian design.	Lie, 2016	1

4.5.3 Key themes and findings

At the end of this section Table 4.4 shows the key themes of DfSS that were derived from the literature. As shown in the table, many authors point towards similar themes and these are regarded as important building blocks of DfSS. Some of the themes have implications for the design process (e.g. systemic, local, distributed etc.), whereas other themes are related to expected design outcomes (e.g. wellbeing, manufacturability, affordability etc.). The themes identified in Table 4.4 provide a basis for the conceptual development of DfSS. The following section will discuss these themes and the main findings of the articles.

Above all, the literature makes clear that design has an important role to play in promoting social sustainability. Among the earlier works, Margolin (1998) quotes Papanek's claim that "*industrial design has put murder on a mass-production basis*" and calls on designers "*to envision and give form to material and immaterial products that can address human problems on a broad scale, and contribute to human well-being*". The view that design is both a source of un-sustainability and an important means for achieving sustainability is repeated throughout the literature (Cooley, 1986; Margolin, 1998; Margolin & Margolin, 2002; Morelli, 2012). Whilst many authors are critical about mainstream design, they are also hopeful that the growth of 'design activism' signals a new era of designers who are more conscious of their impacts on society (Lie, 2016; Margolin, 1998; Ramirez, 2011).

McMahon & Bhamra (2015) suggest that complex challenges can be reframed as opportunities for meeting people's needs and Chick (2012) proposes that design can trigger, facilitate and scale up social impact. Nonetheless, design is specifically criticised for overlooking the social dimensions of sustainability (Bhamra et al., 2013; Margolin, 1998; McMahon & Bhamra, 2011, 2015). According to Bhamra et al. (2013) the neglect of social sustainability has undermined the search for much-needed solutions. They argue that social factors must be included in order to transition from incremental to systems wide innovation. McMahon & Bhamra (2011; 2015) emphasise that addressing social sustainability is a difficult but urgent task to bring about sustainable development.

An important finding from the literature is that DfSS requires a holistic approach, which is long-term and open-ended. Sustainability must embedded early on and designed 'into' solutions (Thomas, 2006; Lilley, 2009). Bjögvinsson et al. (2012) set out the need for a long-term, holistic outlooks that shifts design from *projecting* to *infrastructuring*. Whereas projects have fixed timespans and pre-defined goals, *infrastructuring* focuses on long-term commitments and is naturally open-ended. Bjögvinsson et al. (2012) also discuss the shift from designing *things* or objects to *Things* or socio-material assemblies. Elsewhere, this discussion can be found in the call for a product-service systems approach (Vezzoli, 2006; Vezzoli et al., 2015). In their discussion of the Mälmo Living Lab, Bjögvinsson et al. (2012) explain the transformation of one *Thing* to another *Thing*. Design does not end with the creation of a product but is an ongoing process of relationship building between different actors. DfSS is thus firmly positioned as an ongoing and open-ended process.

Other authors underline that strong sustainability requires systems change (Ceschin & Gaziulusoy, 2016; Melles et al., 2011; Vezzoli, 2006). According to Dewulf (2003) and Maxwell & van der Vorst (2003) a full-life cycle approach is needed from the cradle to the grave. Some authors call for radical changes in global production and consumption to achieve this (Melles et al. 2011). Koo & Cooper (2016) point out the inherent tension between the ethical designer and the designer for consumerism. On the other hand, Gamman & Thorpe (2006) contend that social design is not necessarily opposed to market-based design, and Koo (2016) argues that socially responsible design must integrate market-led, designer-led and regulation-led design.

Reflecting on radical versus incremental approaches to social design, Koskinen & Hush (2016) distinguish between three different models of social design. To begin with, they introduce utopian design as the mainstream approach. In their opinion, utopian design is mainly inspired by Papanek's (1985) vision of a 'Good Society' which argues that "*good design should not be the prerogative of the rich North only*". They criticise this approach for imposing exogeneous views of a 'Good Society', and suggest two feasible alternatives: molecular and sociological design. Molecular design is focused on changing society incrementally, without a larger vision. This approach tends towards bottom-up, small scale change. In contrast, sociological design targets social structures and social inequalities, as well as the practices that uphold them. In conclusion they suggest that these approaches are not necessarily mutually exclusive. These findings suggest that DfSS should adopt a holistic outlook that iterates between broad and narrow thinking.

Another key finding from the literature on DfSS is that design is contextual and therefore must be locally driven (Stairs, 2005). This is consistent with views that sustainability itself is contextual (Waage, 2007) and that design is situated (Bezerra & Brasell-Jones, 2005), dialogical (Cipolla & Bartholo, 2014) and dynamic (Calvo & De Rosa, 2017). Manzini (2011) emphasises the importance of connecting local and global knowledge, advocating for a design practice that is small, local, open and connected. This approaches marks a shift towards a new regime that is that is more resilient and sustainable (Manzini, 2015). Similarly, Morelli (2007) highlights the symbiotic relationship between local and global design, and Vezzoli (2006) advocates for local, collaborative and network-based initiatives. Specifically, these authors reflect on applications of digital technologies that are enabling more connected and collaborative networks. Such network approaches may go some way to addressing concerns that DfSS is limited by its 'small scale approach' and that there are a lack of scalable models (D.-S. Chen et al., 2016).

The new emphasis on endogenous design also necessitates a change in attitudes towards the 'local'. Er & Kaya (2008) highlight the phenomenon of late-comer industrialisation in developing countries, suggesting that modernist development paradigms which focus on importing technologies have undermined local knowledge. They focus on the history of design in Turkey to reveal that local knowledge and skills have been regarded as inferior and therefore limited the potential for local development. Among the papers that focus on design in the Global South, local ownership is a key theme. Thomas (2006) highlights that many designs which were aimed at alleviating poverty failed because local communities did not take ownership of them. In a similar vein, De Vere et al. (2011) call on design to empower communities and Melles et al. (2011) advocate a bottom-up approach that supports local control. It is clear that DfSS must support the agency of local actors, i.e. the capacity of local actors to act independently (Caruso & Frankel, 2010; Kang, 2016). Shifting from the status quo to a more locally-driven model will require a change in attitudes and the creation of new platforms to mobilise local resources (Morelli, 2012).

Going hand in hand with calls for more locally-driven design, is the view that DfSS is participatory and democratic (Bjögvinsson et al., 2012; Hillgren et al., 2011; Manzini, 2011; R. C. Smith & Iversen, 2018; Thorpe & Gamman, 2011). R.C. Smith & Iverson (2018) propose that participatory design can offer far-reaching impacts through the creation of tangible artefacts, development of new skills and new ways of seeing the world. Lie (2016) explains the integrated history of co-design and social design to argue for more participatory design approaches, which attempt to involve all the affected stakeholders in the design process. Manzini (2013) claims that social innovation is necessarily participatory. This builds on related approaches such as inclusive design and universal design, which promote the perspectives of multiple actors (Kadir & Jamaludin, 2013).

Many of the papers also consider the changing role of the designer in participatory design. Calvo & De Rosa (2017) specifically examine community co-design from the perspective of DfSS. They analyse how the design of community spaces strengthens relationships between people and places. Calvo and De Rosa (2017) suggest a close relationship between participatory design and social sustainability, however they do not provide a proper discussion of DfSS. In other work, Kang (2016) positions the designer as a device that can facilitate the design process and empowers participants to use their tacit knowledge. Thorpe & Gamman (2011) contend that the designer should assume a more active role as a co-actor, which is consistent with Manzini's (2015b) criticism of 'post-it design' in which design experts are relegated to administrative actors. On the whole, however, the literature is vague in describing exactly how participation should happen. Thorpe & Gamman (2011) suggest a possible maternalistic model (whereby the designer provides 'small doses of help') and a fraternalistic model (that democratises responsibility) to replace paternalistic approaches. At the same time, they highlight that totally participatory approaches are unrealistic and unnecessary. As they put it: "*we argue that as designers working within complex social design scenarios we can seek consensus and create conditions that foster it, but we cannot force it – and that has to be good enough*." For DfSS, this highlights the importance of supporting collaborative approaches whilst recognising its limitations.

Capacity building is identified as another important part of DfSS. In general, Thorpe & Gamman (2011) recommend that design should shift its focus from *fixing problems* to *building capacity*. Similarly, Tromp & Hekkert (2016) suggest that problems can be reframed as phenomena to reflect this changing scope. Several authors identify capacity building and education as a key driver of impact (Amatullo et al., 2011). For Bjögvinsson et al. (2011) capacity building is directly related to participatory design, another key theme of DfSS. Melles et al. (2011) take this further to suggest that design should create employment, alongside the advancement of local skills.

Amatullo et al. (2010) present a social impact project in Guatemala that aims to create employment for women through the production and sale of traditional textiles. Education and financial independence are highlighted as key enablers of social impact. Similarly, Thomas (2006) emphasises the importance of financial independence in the description of a project to manufacture cookstoves in Kenya. He explains that the women who produce the stoves have benefited both economically and socially through their ability to make a 'decent income'.

Elsewhere, Cooley (1986) puts forward that design should expand human capacity: "*design, manufacture and use [should] enhance human skill and ingenuity… and help human beings rather than control, deskill and maim them.*" Cooley is particularly fearful about technology that subjugates workers. In a similar vein, Bezerra & Brasell-Jones (2005) emphasise freedom as a key dimension of sustainability. They draw on the philosophy of Karl Popper to argue that education in inherently related to freedom, and only through education can people understand the limits of their freedom.

From another perspective, it is understood that in order to progress DfSS new design competencies must be cultivated. Several papers explore ways to embed social sustainability into design education. McMahon & Bhamra (2011) reflect on how collaborative design projects can help integrate social sustainability into student design practice. They explore the design competencies required by students to Design for Social Sustainability. In later work, they conduct a delphi study to identify that reflection, dialogue, engagement and flexibility are key design competencies (McMahon & Bhamra, 2015). Other research emphasises the importance of developing design ethics and virtues as part of a responsive design practice (De Vere et al., 2009; Haug, 2017; Koo & Cooper, 2016; Lilley & Wilson, 2013). Moreover, empathy is recognised as a fundamental competency that enables designers to create more sustainable solutions (Caruso & Frankel, 2010; Schaber, 2010; Sklar & Madsen, 2010). Finally, Asheim et al. (2012) suggests that introducing design students to social issues, before environmental ones, provides an effective introduction to sustainability. In total, it is clear the DfSS necessitates the capacity building of both expert and diffuse (non-expert) designers (Manzini, 2015b).

Most of the papers take a broad view of DfSS and do not indicate requirements for specific product features. However, there is the clear expectation that any solution must enhance wellbeing and reduce harm. Haug (2017) reflects on the reality that design can cause harm, and specifically calls on ethical designers to mitigate harm across all stages of a product's lifecycle. Bezerra & Brasell-

Jones (2005) argue the case for the responsible designer who seeks to prevent harm. Gould et al. (2017) specifically define socially sustainable product development as the "*processes and practices that lead to products whose lifecycle have a less negative impact on the social systems*". Taking this further, Mendoza et al. (2019) identifies that design should actively promote wellbeing, positioning products as 'wellbeing enhancers'.

Several articles emphasise the importance of needs-based design to fulfil these ambitions. For example, Melles et al. (2011) identify the fulfilment of needs as a primary success criteria for design. Margolin & Margolin (2002) draw on practices from social work to define a new model of design based on social need. Cipolla & Bartholo (2014) build on this work to propose a dialogical, needs-based approach that is situated and contextual. Other authors recommend that products should be inclusive (Cipolla & Bartholo, 2014; Kadir & Jamaludin, 2013), usable (Melles et al. 2011) and affordable (Melles et al., 2011; A. Thomas, 2006).

Finally, the lack of established metrics, methods and tools is noted as a key challenge for DfSS (Gmelin & Seuring, 2014; Hanusch & Birkhofer, 2010). Margolin (1998) believes that design would benefit from more normative approaches and Waage (2007) calls for a roadmap that integrates sustainability with design. Addressing the lack of practical tools, Hanush & Birkhofer (2010) focus on methods to support social sustainability in product development. Although they fall short of providing an actual tool, they identify a process for doing so based on analysing a variety of socially sustainable products. Maxwell & van der Vorst (2003) propose a sustainable product and service development method for assessing products based on triple bottom line principles. However, they adopt a fairly narrow view of social impact that is mainly focused on health and safety, and neglects the more expansive definition of social sustainability that now exists. Similar criticisms can be applied to Howarth & Hadfield's (2006) tool for assessing social and environmental sustainability of products. Dewulf (2003) and Gmelin & Seuring (2014) both investigate the potential for a life-cycle analysis tool that considers social impacts, however they fail to provide a comprehensive tool for evaluation. Woodcraft (2015) provide an assessment framework for urban design projects based on the dimensions of social and cultural life, voices and influence, and amenities and infrastructure. She creates a set of industry-specific indicators for each dimension and a tool for scoring each indicator.

Gould et al. (2017) are concerned with new ways to support concept selection in the design process. They develop an assessment tool to support socially sustainable product development by deriving social sustainability indicators from existing principles and frameworks. They use these indicators to compare two concepts for the aerospace industry, however they find that the tool is not accurate enough to enable the selection of most ‘socially sustainable’ concepts. Melles et al. (2011) provide a promising starting point, putting forward a list for evaluating socially responsible design, including: need, suitability, relative affordability, advancement, local control, usability, dependency and empowerment. Finally, Mendoza et al. (2019) does not define social sustainability, but considers the following four aspects when analysing the social sustainability of a solar cooker: wellbeing, participation, product emotional durability, and behaviour changes towards sustainability. These efforts underline the complex but necessary task of creating metrics, methods and tools for supporting DfSS.

Table 4.4 – Key themes emerging from the literature

Theme	Sub-Theme	Citations
Systemic	Long-term approach	Björgvinsson et al., 2012; Clark et al., 2009; Cooley, 1986; Hillgren et al., 2011; Stairs, 2005
	Systemic/holistic	Bhamra et al., 2013; Ceschin & Gaziulusoy, 2016; Chick, 2012; Cipolla & Bartholo, 2014; Clark et al., 2009; Cooley, 1986; De Vere et al., 2009, 2011; Howarth & Hadfield, 2006; Koskinen & Hush, 2016; Manzini & Vezzoli, 2003; Melles et al., 2011; Stairs, 2005; Vezzoli, 2006; Vezzoli et al., 2015
	Catalyses social change	Gamman & Thorpe, 2006
	Full-life cycle	Dewulf, 2003; Maxwell & van der Vorst, 2003
	Product and process	Hanusch & Birkhofer, 2010
Local	Local design	Manzini, 2011, 2013, 2015a; Melles et al., 2011, 2015; Morelli, 2007, 2012; Thorpe & Gamman, 2011; Vezzoli, 2006
Distributed, connected	Distributed design/networks	Manzini, 2011, 2015a; Melles et al., 2015; Morelli, 2007, 2012
	Open/connected	Manzini, 2011, 2015a
	Small/local scale	Chen et al., 2016
Contextual	Local suitability	Amatullo et al., 2010; Asheim et al., 2012; Björgvinsson et al., 2012; Chick, 2012; Cipolla & Bartholo, 2014; Cooley, 1986; Gmelin & Seuring, 2014; Hillgren et al., 2011; Kang, 2016; Manzini, 2011, 2015a; Margolin & Margolin, 2002; McMahon & Bhamra, 2015, 2015; Melles et al., 2011, 2015; Morelli, 2012; Stairs, 2005
	Culturally sensitive design	De Vere et al., 2011; Kadir & Jamaludin, 2013; Margolin, 1998; Vezzoli, 2006; Woodcraft, 2015
	Appropriate technology	Lie, 2016; Sklar & Madsen, 2010

	Situated design	Cipolla & Bartholo, 2014; Kang, 2016
Empowerment	Empowering/ emancipatory	Amatullo et al., 2010; Bezerra & Brasell-Jones, 2005; Caruso & Frankel, 2010; Cipolla & Bartholo, 2014; Cooley, 1986; R.C. Smith & Iversen, 2018
	Local control/ local ownership	De Vere et al., 2011; Melles et al., 2015
	Agency	Er & Kaya, 2008; Kadir & Jamaludin, 2013
Participatory	Participatory/ democratic	Amatullo et al., 2010; Asheim et al., 2012; Bjögvinsson et al., 2012; Chen et al., 2016; Chick, 2012; Cipolla & Bartholo, 2014; Cooley, 1986; De Vere et al., 2011; Hillgren et al., 2011; Kang, 2016; Manzini, 2011, 2015a; Margolin, 1998; Margolin & Margolin, 2002; Melles et al., 2011, 2015; Mendoza et al., 2019; Morelli, 2012; R.C. Smith & Iversen, 2018; Stairs, 2005
	Collaborative/ cooperative	Cooley, 1986; Gmelin & Seuring, 2014; McMahon & Bhamra, 2011, 2015; Melles et al., 2011
	Bottom up	Manzini, 2013; Melles et al., 2015
	People focussed/ relational	De Vere et al., 2011; Hillgren et al., 2011
Responsive	Reflective	McMahon & Bhamra, 2011
	Empathetic	Caruso & Frankel, 2010; Cipolla & Bartholo, 2014; Schaber, 2010; Sklar & Madsen, 2010
	Ethical	Koo, 2016; Koo & Cooper, 2016
Employment, skills and education	Job creation/ employment	Amatullo et al., 2010; Cooley, 1986; Melles et al., 2011; Thomas, 2006
	Educational/ advancing local knowledge	Amatullo et al., 2010; Bezerra & Brasell-Jones, 2005; Bjögvinsson et al., 2012; Melles et al., 2011; Morelli, 2012
	Capacity building	Yee & White, 2015
Wellbeing	Needs-based	Cipolla & Bartholo, 2014; Cooley, 1986; Margolin & Margolin, 2002; Melles et al., 2011; Rose, 2016; Thomas, 2006
	Preventing harm/ reducing harm	Bezerra & Brasell-Jones, 2005; Haug, 2017; Thomas, 2006
	Promoting wellbeing	Mendoza et al., 2019
Product-led	Product-led	Lilley, 2009
Manufacturability	Manufacturability	Thomas, 2006
Affordability	Affordability	Melles et al., 2011; Thomas, 2006
Financial independence	Financial independence	Amatullo et al., 2010; Cooley, 1986; Thomas, 2006
Usability	Usability	Melles et al., 2011
Inclusivity	Inclusive	Cipolla & Bartholo, 2014; Kadir & Jamaludin, 2013
	Accessibility	Kadir & Jamaludin, 2013

4.6 Reflections on the literature

In order to conceptually develop DfSS, a systematic literature review was undertaken to gather relevant literature. Specifically, this review looked at the intersection between social design and sustainable design literature, to build up an understanding of DfSS. It considered related fields such as socially responsible design, socially useful design and design for sustainability, which are broad but occasionally touch on DfSS. Within the literature, it was noted that articles frequently used different social/sustainable design terminology synonymously and that there often lacked consensus about their precise definitions. This chapter has helped to synthesise this fragmented knowledge as a first step towards better understanding DfSS.

Whilst this research positions DfSS as complementary to existing knowledge on social and sustainable design, it should be viewed as distinct to other social/sustainable design approaches. In answer to possible concerns that DfSS is just *another* approach that will further fragment knowledge, two main points are raised. First, DfSS is already being used in academia and in practice, albeit with little conceptual clarity or consistency. Second, DfSS is unique in its explicit focus at the intersection of social and sustainable design perspectives. Whereas social issues are often considered as an afterthought in integrated sustainability models, DfSS positions social factors as a fundamental starting point for sustainability. In comparison with other social design approaches, DfSS is broader in outlook and is naturally focused on longer term horizons. Whereas the majority of social design practices focus on the creation of products that create social impact (or at least limit negative impact), DfSS goes further to explicitly advocate for design that that leads to the preservation of social systems and the removal of fundamental obstacles that destroy these systems. DfSS pays particular attention to the need for equity between current and future generations in bringing about human wellbeing and flourishing. In addition, DfSS recognises the weaknesses of earlier social design approaches. It is cognisant of the criticisms that social design has too-often imposed an exogeneous view of development. DfSS thus acknowledges the need for a multi-faceted approach to history, traditions and dialogue (McMahon & Bhamra, 2011).

Finally, in this thesis DfSS is considered to be a catalyst for impact in DF4D projects. Whilst previous design and social design movements are largely focused on the design of products or systems, in this thesis DfSS is studied with reference to DF4D projects, that is ongoing interventions that aim to alleviate humanitarian and development problems.

4.7 Summary of the chapter

This chapter has helped to establish a theoretical foundation for DfSS. It was explained that although design is widely recognised as an important change agent, it has been largely neglected in research on social sustainability. A systematic literature review was conducted, drawing on literature from social and sustainable design in order to conceptually develop DfSS. The main findings of these articles were carefully analysed and several key themes of DfSS were derived. These themes provided an initial understanding of the constituent parts of DfSS. In discussion, the chapter reflected on potential concerns that DfSS is just *another* approach that will further fragment knowledge in an already chaotic field. It was shown that DfSS is clearly distinct from existing sustainable and social design approaches, and indeed that DfSS is already being used by academia and practice. In summary, this chapter contributes to the conceptual development of DfSS that will guide the following stages of the research.

Chapter 5 An analytical approach to DfSS in DF4D

5.1 Introduction

The previous chapter provided a theoretical foundation for DfSS, by identifying some key themes of DfSS. It was explained that DfSS is design that leads to the preservation of social systems and the removal of fundamental obstacles that destroy these systems; DfSS is design that supports human wellbeing and flourishing now and in the future. This chapter addresses the problem discovered in Chapter 3 that there are scarce resources available to support DfSS, and that this is limiting the success of DF4D projects. It builds on existing knowledge from the literature and presents a detailed case study of three healthcare DF4D projects in order to develop a practical framework for DfSS. This framework provides useful guidelines to help plan and evaluate DF4D projects. Section 5.2 explains the methods used. Section 5.3 introduces the DfSS in DF4D framework. Section 5.4 evaluates the case studies using this framework to demonstrate its value. Section 5.5 discusses the main findings, including the practical and theoretical implications of the framework. Section 5.6 concludes the chapter, and sets out the need for additional perspectives to explore DfSS in DF4D.

Parts of this chapter have been published in Corsini & Moultrie (2019).

5.2 Methods

5.2.1 Data collection

In order to address the lack of support for designers working on DF4D projects, it was decided to create a DfSS framework that could help guide the planning and evaluation of projects. In the previous chapter a working list of DfSS themes was identified from the literature. In order to explore the relevance of these themes to the DF4D context, three DF4D case studies were selected.

Multiple case studies are a well-recognised way of gathering data about an emerging phenomenon (Yin, 2018). The case studies were selected from a shortlist of case studies identified in the exploratory study. One case study was added to this shortlist after attending a relevant conference in the field. Case studies for this main study were selected based on the following criteria. First, the case study should focus on DF4D in the Global South. Second, the case study should be ongoing for sufficient duration to gather detailed 'live' data. Third, collectively the case studies should be related to a similar industry. In the exploratory study it was discovered that the majority of applications were in *healthcare* and so this was chosen as a key focus. Finally, as a group the case studies were chosen to represent DF4D projects in a range of organisations. For example, Field Ready is a non-governmental organisation (NGO); the Biomedical Engineering and Technology Incubation Centre (BETiC) at the Indian Institute of Technology Bombay (IIT-B) is a research institution; and, FabLab/MakerSpace Nairobi is a makerspace.

Initial interviews were conducted with various members of the organisations over an eight month period to build up an understanding of the case studies. The researcher visited case studies one (CS1) and two (CS2) between April and May 2018 and visited case study three (CS3) in September 2018. The purpose of this data collection was two-fold. First, interviews were conducted with designers and project managers to identify the key themes of DfSS in the DF4D context. These interviews focused on identifying the perceived barriers and enablers of social sustainability, and uncovering the design processes and practices that promote social sustainability. This data was used to develop the DfSS in DF4D framework, which is presented later in the chapter. Second, information was gathered on the actual implementation of the DF4D projects, by conducting in-field observations and interviews with a range of stakeholders including partners, end users and beneficiaries. These interviews focused on the participants' involvement with the project, and their perception of the positive and negative impacts of the project on human wellbeing and flourishing, now and in the future. Table 5.1 lists the interviewee details and indicates which interviews contributed to the development of the DfSS in DF4D framework and to the evaluation of the case studies. The full interview protocols can be found in Appendix Tables 1 and 2. Other sources of data including documents, news reports and physical products were also used to triangulate data, in an effort to improve the evaluation of the case studies. Direct observation played an important role and photographs were taken to help convey the important characteristics of the case studies (Dabbs, 1982). No translation assistance was required in CS1 or CS3. In CS2, an experienced translator provided translation of some interviews from Hindi to English. All the interviews were translated live to guide the researcher and they were fully translated and transcribed verbatim afterwards by the translator. This provided rich data to later evaluate the DF4D projects using the DfSS framework.

Table 5.1 – Interviewee details and codes

Case Study	**Interviewee Roles and Codes**	
	Building the DfSS framework *(interviews with designers/ project managers)*	Evaluating the case studies *(interviews with all stakeholders)*
CS1. Field Ready	Project manager (CS1-01), Designer (CS1-02), Designer (CS1-03), Junior designer (CS1-04), Junior designer (CS1-05), Monitoring and evaluation lead (CS1-06), Innovation Advisor (CS1-07)	Project manager (CS1-01), Designer (CS1-02), Designer (CS1-03), Junior designer (CS1-04), Junior designer (CS1-05), Monitoring and evaluation lead (CS1-06), Innovation Advisor (CS1-07)
CS2. Biomedical Engineering and Technology incubation Centre (BETiC) at Indian Institute of Technology-Bombay (IIT-B), Ratna Nidhi Charitable Trust (RNCT) Mumbai, Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS) Jaipur	Project lead and engineer at IIT-B (CS2-01), Physiotherapist at IIT-B (CS2-02), Designer at IIT-B (CS2-03), Junior designer at IIT-B (CS2-04), CEO at RNCT (CS2-05)	Project lead and engineer at IIT-B (CS2-01), Physiotherapist at IIT-B (CS2-02), Designer at IIT-B (CS2-03), Junior designer at IIT-B (CS2-04), CEO at RNCT (CS2-05), Prosthetist and Orthotist at RNCT (CS2-06), Production technician at RNCT (CS2-07), Production technicians at RNCT (CS2-08), Beneficiary 1 at RNCT (CS2-09), Beneficiary 2 at RNCT (CS2-10), CEO, founder of BMVSS (CS2-11), Technical consultant at BMVSS (CS2-12), Prosthetist and Orthotist at BMVSS (CS2-13), Technician at Jaipur Foot (CS2-14), Project manager at BMVSS (CS2-15), Secretary at BMVSS (CS2-16), Beneficiary 1 at BMVSS (CS2-17), Beneficiary 2 at BMVSS (CS2-18), Beneficiary 3 at BMVSS (CS2-19), Beneficiary 4 at BMVSS (CS2-20), Beneficiary 5 at BMVSS (CS2-21), Beneficiary 6 at BMVSS (CS2-22)
CS3. FabLab/ MakerSpace Nairobi, Kenyatta National Hospital (KNH)	MakerSpace manager and designer (CS3-01), Lead designer at MakerSpace (CS3-02), Designer at MakerSpace (CS3-03), Project manager at KNH (CS3-04)	MakerSpace manager and designer (CS3-01), Lead designer at MakerSpace (CS3-02), Designer at MakerSpace (CS3-03), Project manager at KNH (CS3-04), Project

	administrator at KNH (CS3-05), Project data manager at KNH (CS3-06), Deputy head nurse at KNH (CS3-07), Biomedical engineer at KNH (CS3-08)

5.2.2 Data analysis

Figure 5.1 shows how the case studies built on the findings in Chapter 4, to enable the development of the DfSS in DF4D framework. It illustrates how data was also used to subsequently evaluate the case studies using the DfSS in DF4D framework.

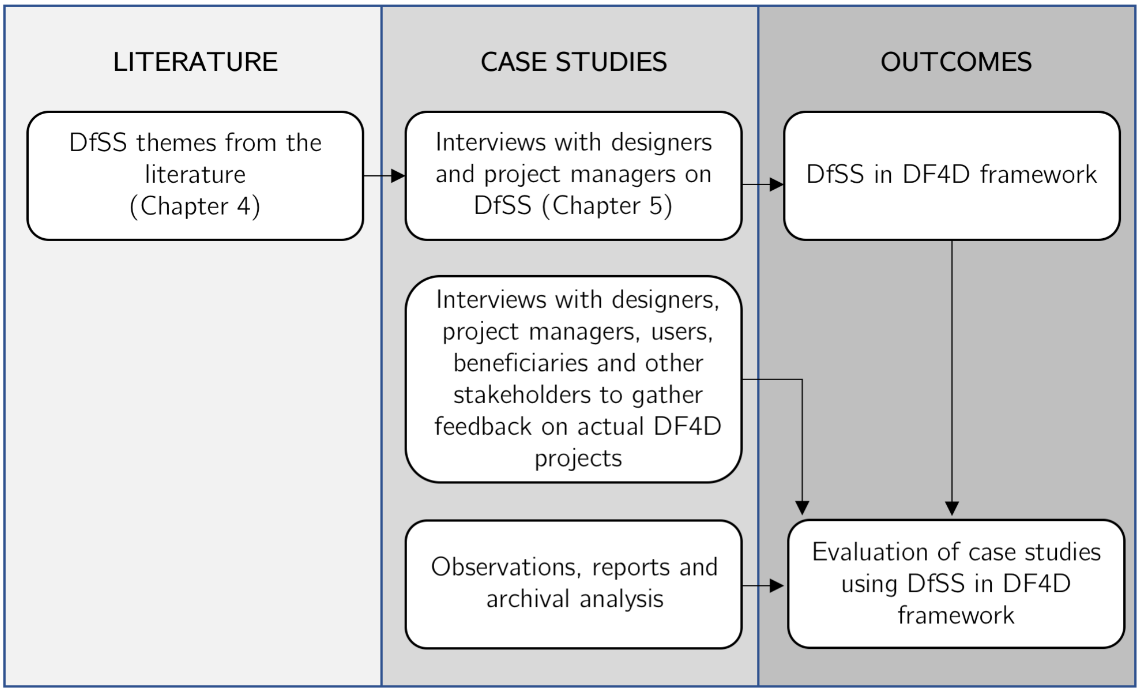

Figure 5.1 – Approach for creating the Design for Social Sustainability (DfSS) in Digital Fabrication for Development (DF4D) framework, and using it to evaluate the case studies

5.2.2.1 Building the DfSS in DF4D framework

The DfSS in DF4D framework built on the findings in the previous chapter and was developed through several rounds of qualitative coding of the case study data. Initially the interviews with the designers/project managers focussing on DfSS were translated verbatim and imported into MAXQDA for analysis. A code hierarchy was created based on the ‘working list’ of DfSS themes, identified from the literature in Chapter 4. This included 15 themes and 36 sub-themes. During the first cycle of coding, line by line coding of the interview transcripts was conducted (Johnny Saldaña, 2009), resulting in 448 coded segments. Additional codes were created, and existing codes were also updated to reflect the particular focus and language used in the interviews. For example, the theme 'contextual' in the literature was renamed 'suitability'. During the second cycle of coding, further grouping and refinement of the codes was conducted.

Table 5.2 illustrates how the case study interviews helped to validate, clarify and expand on the working list of DfSS themes derived from the literature. In some instances, the interviews provided greater insight into particular themes. For example, 'local' was identified as an important building block of DfSS in the literature. However, the case studies specifically clarified the importance of local manufacture and local control and repair in the DF4D context. Some themes were also not recognised by the interviewees and so were removed. Specifically 'responsive' (meaning ethical design intent), was perceived by the interviewees to be too ambiguous and so was removed. 'Product-led' was considered to be a general term that could refer to several other factors, and so was also removed.

Table 5.2 – Themes of DfSS from the literature and related findings from the case studies

Themes of DfSS from literature	**Related findings from case study interviews**
Systemic	Confirmed the importance of systemic thinking.
Local	Confirmed the importance of the 'local'. Emphasis on the importance of local manufacture and local control and repair.
Distributed, connected	Emphasis on collaborative and transparent design practices.
Contextual	Emphasis on ensuring that projects are suitable for social, cultural and environmental context. Recognition of the need for adjustability, according to the changing context.
Empowerment	Confirmed the importance of empowerment.
Participatory	Emphasis on collaboration with different stakeholders.
Responsive	Too ambiguous, factor removed.
Employment, skills and education	Confirmed the importance of advancement of the local community. Emphasis on capacity building and employment.
Wellbeing	Emphasis on human need and dignity.
Product-led	Too general, factor removed.
Manufacturability	Emphasis on scalability and replication.
Affordability	Recognition that affordability is an important factor in determining product access (now and in the future).
Financial independence	Emphasis on employment as a means for financial independence.
Usability	Confirmed the importance of product usability.
Inclusivity	Confirmed the importance of inclusive design. Emphasis on access for traditionally marginalised groups.

The second round of thematic coding aimed to further group and reduce the amount of codes. For example, the codes 'autonomy' and 'independence' were grouped under the code 'empowerment'; the codes 'replicable', 'scalability' and 'manufacturability' were grouped under the code 'scalable'. This resulted in sixteen key themes of DfSS, validated for the DF4D context. Figure 5.2 shows the linkages between the working list of DfSS themes from the literature, and the DfSS themes that resulted following the case studies. Overall, there is a close mapping between the themes from the literature and the themes emerging from the case study data. Two additional themes 'quality' and 'complementary' were added to reflect the frugal mindset of designers in the DF4D context, which had not been captured in the original themes of DfSS. The sixteen factors were each given a description to help communicate their meaning. It was decided that these descriptions should be posed as prompt questions to assist with the development of a practical framework. For example, the factor 'Advancement' was described using the following questions: 'Does it create jobs in the country? Does it build on existing skills? Does it develop new skills?'

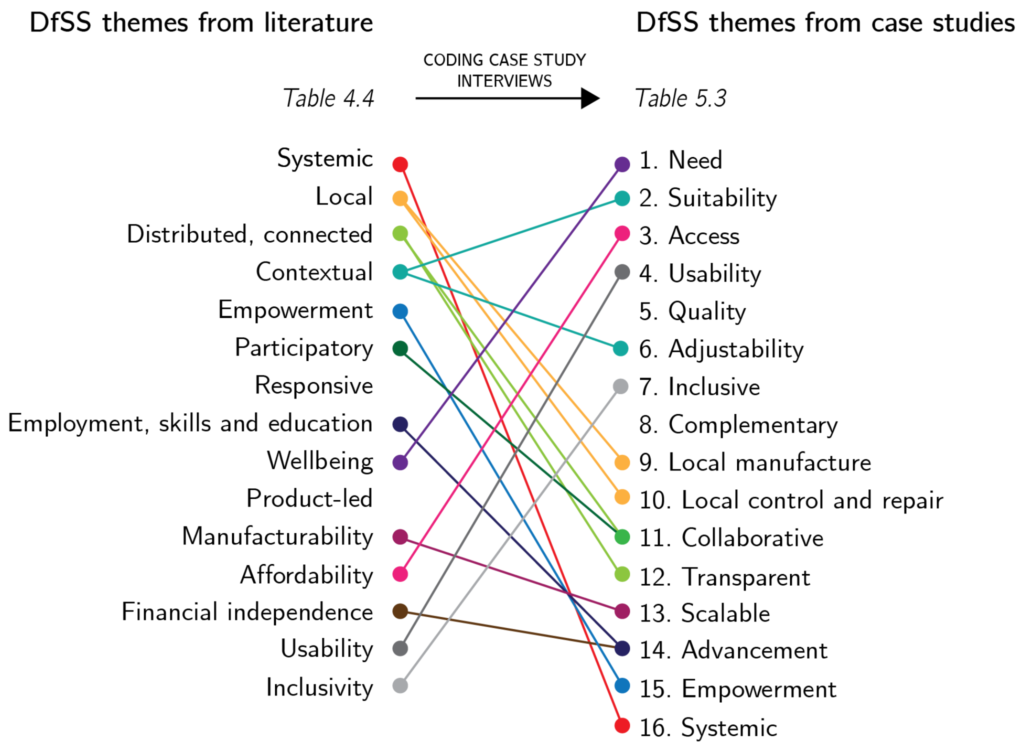

Figure 5.2 – Linkages between the themes of DfSS derived from the literature and the themes of DfSS emerging from the case studies

The final round of thematic coding focused on exploring the relationships between the sixteen codes. After careful reflection, it was found that the sixteen factors could be broadly grouped in three categories. The first set of factors were directly concerned with the physical product's attributes and were called *product* factors. The next set of factors were related to the management of the design process and were grouped as *process* factors. The final set of factors facilitated new ways of doing things or thinking about things and formed the category *paradigm* factors. Table 5.3 lists these factors and provides exemplary quotes from the interviews that were used to justify these themes.

Table 5.3 – Exemplary quotes to justify the DfSS framework

	Factor	Exemplary Quotes
PRODUCT FACTORS	1. Need	"Obviously, addressing the need is where we start and hopefully finish. There has to be an understanding of the problem that needs to be solved and how your intervention and your approach is actually addressing that problem. I said we're focusing on products, but actually those products are a reflection of how we are addressing a need." CS1-01
	2. Suitability	"Sometimes when you make something you make it to suit a certain environment. So it works well in that environment, but it may not work very well in a different setup. So that's also part of it, you want to make sure that you're making devices that will work and will be sustainable in our local setup because our setup might be very different from the UK or US. So if we buy a machine from a first world country and bring it here, they may not exactly make it or design it to be very resilient to a harsh environment. So once you bring it here and it meets very rough floors maybe, or very harsh temperatures, or saline water, it wasn't designed with that in mind, then it gets here and meets that, it starts becoming rusty, it breaks down." CS3-01
	3. Access	"What we are doing should be accessible to common people and for that, that has to be cost effective." CS2-03
	4. Usability	"They would come to us and say this gauge has to be labelled this kind of way because if it's done that way we have an easy time interpreting what it's saying. This handle has to be here because when it's here it's easy for us to push it around." CS3-01 "We don't have a lot of time to focus on learning. We want to focus more time on treating the patients. So give us an equipment that is very user friendly." CS3-01
	5. Quality	"We couldn't compromise on the quality… It is unacceptable if Company X does the same thing but degrades the quality." CS2-02 "It has to be long-lasting in terms of the material that have been used, it has to be robust, that whenever it's hit by, it may still withstand the force." CS3-01 "It is the risk that it can pose to the operator or the patient that is important and we have try to minimise those risks." CS3-03

	6. Adjustability	"It might have some other additional features for long term sustainability, for adjustable conformity. Like we have in our shoes. We have shoe laces so that we can define that tightness of the shoe." CS2-02 "So the ideal situation is that you should be able to replace some of the bits some of the parts, without replacing the whole machine." CS3-02
	7. Inclusive	"Some of them are only walking, some of them in sports, some of them are driving cars, some of them are in different types of jobs, some of them in hilly regions, some of them in villages, some of them in cities… their age and body weight varies… their usage metrics vary… The technology will allow us to create a solution for this." CS2-05 "We should have a spectrum of products, and then depending on the patient's level of activity, needs... they should be able to choose from different products" CS2-02 "We also need to have pressure that is acceptable. Because you place it on the baby's head. So we needed to have pressures that are acceptable to pull out the baby and pressures that were not going to injure the mother" CS3-03
	8. Complementary	"The decisions we have made is empowering the Jaipur Foot rather than replacing it. So it can be redesigned in a way that it can get attached to the Jaipur Foot." CS2-02 "More importance should be given on improving designs than trying to do something totally different." CS2-02
PROCESS FACTORS	9. Local manufacture	"If this can be replicated even in the most remote part of the country, then people might have access to these tools and then they might produce instantly right there when it's needed, rather than making it in Kathmandu and then delivering it to other parts, which leads to this supply mismatch." CS1-02
	10. Local control and repair	"Because equipment that has been designed in another country… may not work for us because we don't know how to maintain them… So we said if we made them locally then it means getting spare parts would be very easy." CS3-01
	11. Scalable	"That's how we come up with the different solutions which can be replicated… which means we have longer term sustainability." CS1-02 "So, we want to make this to be a process, scalable, and easily replicable. That takes care of half of the sustainability." CS2-03
	12. Collaborative	"We recognise problems and then identify the problem and then sit together with the local communities and with them look for the solutions." CS1-02 "We don't have CNC, but when we want those processes in our product development, then we share those problems with the other companies and then collaborate and try to fabricate it." CS1-02 "Different people have different ways of looking at lives… you're given the same problem, they will look at the solution from different angles. When you bring all of these angles together, then you end up with a very good idea that works for everyone." CS3-01
	13. Transparent	"When this model has worked, when everything is positive, then we will document it, share it in the online platforms like Thingiverse… someone in a different part of the world, they can instantly download it in case they

		face such problems, so that someone doesn't have to work on all this process." CS1-02 "We are trying to think of each and every single technical detail or scientific parameter, which when we document that will allow a normal welding guy to replicate the whole process." CS2-03
PARADIGM FACTORS	14. Advancement	"The people who are already employed should be empowered to do that. They should not suffer loss on employment because a new technology is replacing their technology." CS2-02 "There is an opportunity for creation of jobs if we have it locally manufactured. There are a lot of young people who will be employed here… you also got excited because it builds capacity in our students… if as a student, you're working on something like this… you're actually learning on the job." CS3-01
	15. Empowerment	"If we're doing things that then, as soon as we walk away, it all falls to bits, then that's not a model." CS1-06 "No, you will not give you a leg. You are giving life... The leg is an instrument which empowers him for everything around his world. He becomes a man in his own right. In his own eyes, to stand up literally and figuratively on his legs. A leg is only an instrument. But the change we are making to their lives is very, very important." CS2-05
	16. Systemic	"We are helping other local companies and other start-ups to make 3D printers and we are addressing some of the problems, like making 3D printer filaments, doing more research in those fields so that we could offer more affordable and good quality 3D printer filaments locally." CS1-02 "And this was part of that, the aspect of proving a point that as a country we can actually develop this "sophisticated equipment". We just need to give it a shot. Then create an infrastructure that allows that to happen… you don't need to import something from whatever country. You have the idea, you can actually design it in your computer and you can use this printer to make it." CS3-01

5.2.2.2 Evaluating the case studies using the DfSS in DF4D framework

The remaining interviews were transcribed verbatim and imported into MAXQDA for analysis. A code hierarchy was created based on the sixteen factors identified above and used to analyse the interviews. This coding process helped with the retrieval of important information for each case study. In addition, field notes, photographs and internal documents/memos were used to help evaluate the case studies. The researcher used the DfSS in DF4D framework to complete the evaluation of each of the case studies. Each factor was scored red, yellow or green based on the extent to which the case study met that particular criteria. A green score indicated that the factor had been totally or well met by the case study; a yellow score indicated that the factor had been partially met by the case study and that some attention was needed; a red score indicated that the factor had not been met by the case study and that urgent attention was needed. The final analysis for each case study was shared with the relevant organisations and their feedback on the framework's value was collected.

5.3 Introduction to the DfSS in DF4D framework

This section presents the DfSS in DF4D framework aimed at designers and practitioners working on DF4D projects. It is suggested that the framework can help with both planning and evaluating projects, to support decision making. The supporting questions for each factor are intended to encourage reflection. Whilst this framework suggests a way forward for DfSS, the questions are purposely open-ended and qualitative to avoid overly prescriptive criteria that overlook the complex and contextually-dependent realities of DF4D projects.

The DfSS in DF4D framework in Figure 5.3 presents sixteen criteria related to product, process and paradigm factors. Rather than suggesting a hierarchy, it is emphasised that all three categories (product, process and paradigm) must be considered in order to achieve social sustainability. To put it simply, social sustainability cannot exist without addressing all three dimensions from the start of DF4D projects.

The first set of factors in the DfSS framework are related to product itself: need; suitability; access; usability; quality; adjustability; inclusivity; and, complementary. These reflect more incremental approaches to DfSS that focus on user-orientated ways of promoting social sustainability. The second set of factors are related to the design process, including local manufacture; local control and repair; collaborative; transparent; scalable. The final set of factors are related to paradigms: advancement; empowerment; systemic. They demand different ways of doing things and thinking about things. The findings emphasise that as DfSS progresses from product to process to paradigm factors, social sustainability becomes more radical versus incremental, and more system-focused versus user-focused. Figure 5.4 provides a summary of this proposition, which will be discussed in more detail later.

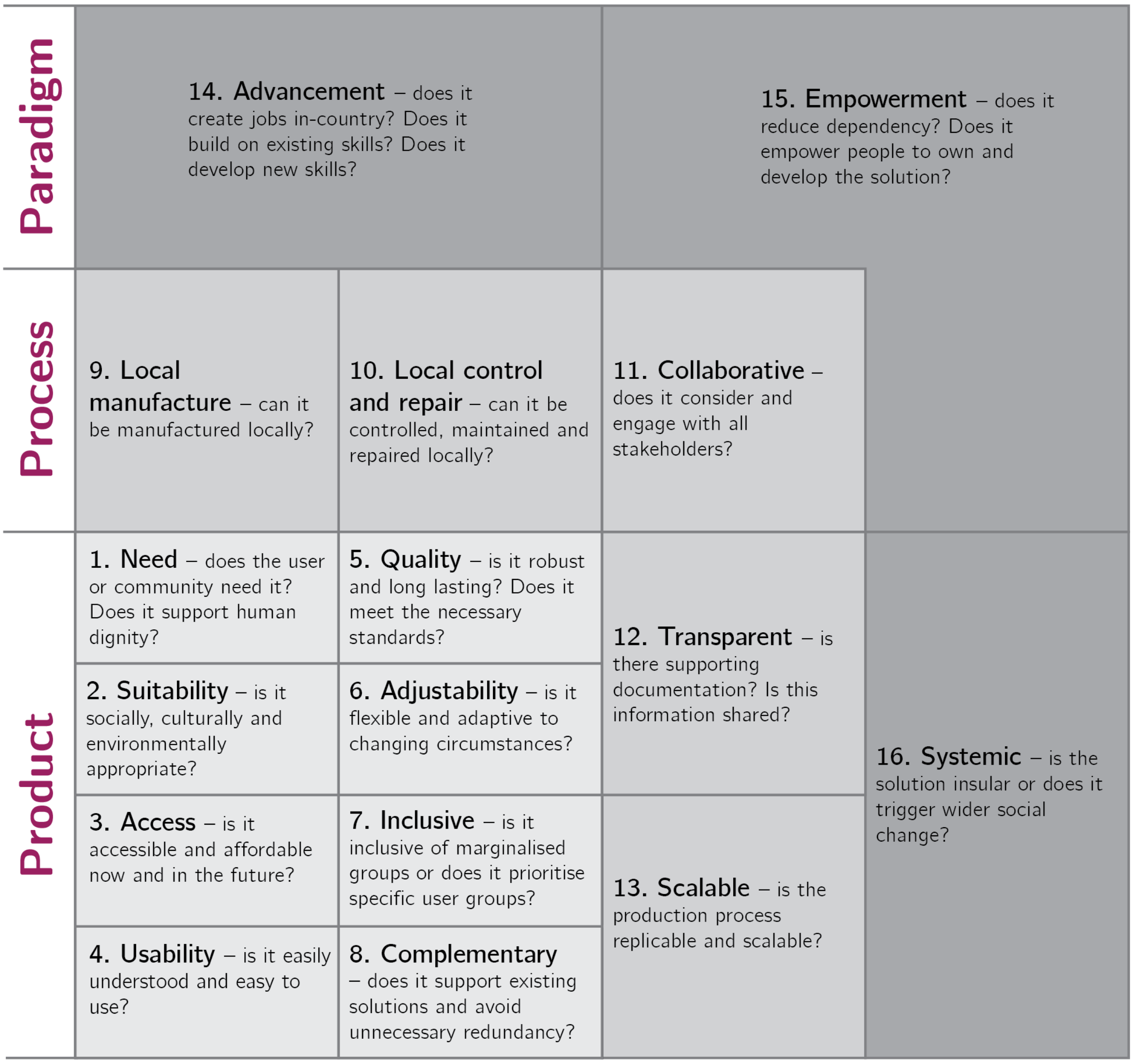

Figure 5.3 – Design for Social Sustainability (DfSS) in DF4D framework

In developing this framework, social sustainability is positioned within environmental and economic sustainability (see Figure 5.4, right hand side). It is suggested that designers can begin by addressing social sustainability, and then consider the impact of their planned DF4D project on environmental and economic sustainability. In other words, practitioners can *start* planning projects by using the DfSS in DF4D framework. They can *then* refer to other existing frameworks to address environmental and economic concerns. For example, Crul & Diehl (2006) present several practical frameworks to support environmental and economic sustainability planning in "Design for Sustainability: A Practical Approach in Developing Economies". Having considered environmental and economic dimensions, practitioners can then *refer back* to the DfSS in DF4D framework and potential trade-offs can be managed. This process of referring back and forth between social, environmental and economic sustainability can be repeated until a balance has been reached between sustainability as a whole. This iterative process that starts with social sustainability, suggests a practical way to manage the three dimensions of sustainability. Figure 5.4 (right hand side) illustrates these feedback loops between social, environmental and economic dimensions. Having now introduced the DfSS in DF4D framework, the following section will demonstrate its value by evaluating the main case studies in this thesis.

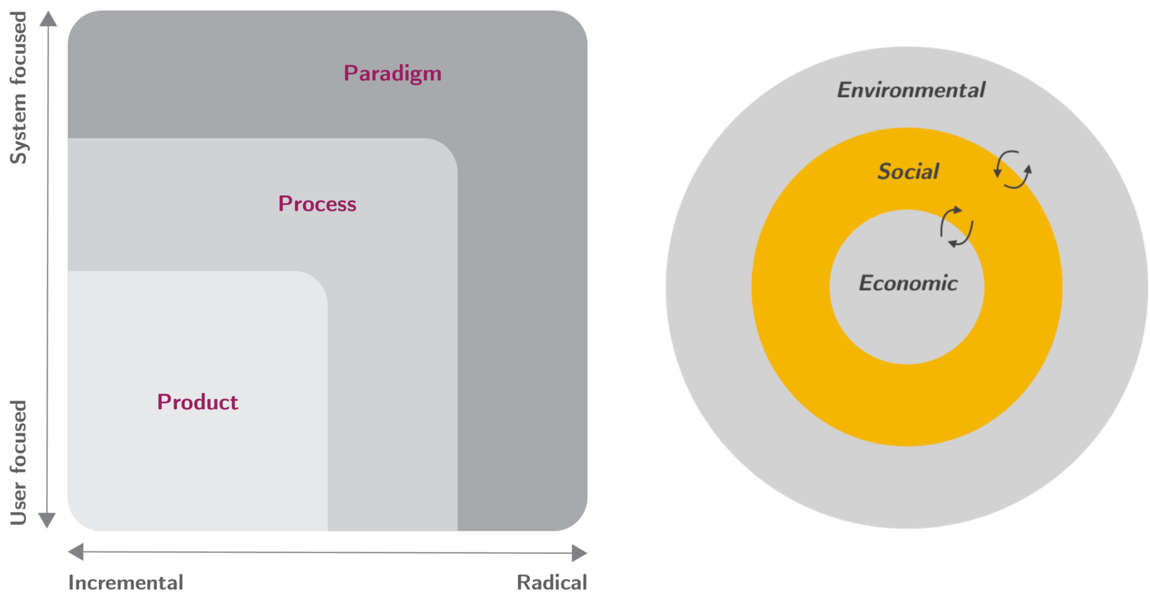

Figure 5.4 – Shifting towards more systems-focused and radical DfSS (left), and positioning DfSS within the broader sustainability context (right)

5.4 Evaluation of the case studies using the DfSS in DF4D framework

5.4.1 3D printed Otoscope by Field Ready

Field Ready is an NGO that is pioneering the use of digital fabrication in the local manufacture of humanitarian supplies in Nepal. Among several products that are in development, they have developed an otoscope, a simple device used in the diagnosis of ear, nose, and throat diseases (see Figure 5.5). The project was selected by Field Ready for evaluation as the organisation believed that it represented a best case example of their work. The project started following a visit to a rural health post in September 2016. They found that clinicians did not have access to otoscopes, because traditional otoscopes were expensive and difficult to procure. A clinician informed Field Ready of a recent instance where he had to rely on his phone torch to examine a child, and that he was unable to correctly diagnose a child with an ear infection. As of May 2018, the otoscope had not been implemented.

Figure 5.5 – 3D printed otoscope (left), and designer working at Field Ready (right)

The otoscope itself was designed to replicate traditional otoscopes, using 3D printing. A major motivation for the project was to improve local *access*. Existing otoscopes are largely unaffordable for rural health posts, and it is estimated that the 3D printed version is 75% cheaper. The device itself was designed to be intuitive to use, adopting a similar design to conventional otoscopes that clinicians are already familiar with (*suitability, usability*). The design itself is intended to be adjustable, so that it can be adapted for other applications (*adjustability*). Field Ready have openly shared the designs for the device on Thingverse and hope that by doing so, it can be made suitable for a wide range of users (*inclusive*). Nonetheless, users need to be made aware of the design and need to have the resources and ability to produce it. A major concern about the otoscope, is that it has not been quality certified (*quality*). Although Field Ready have approached the chamber of commerce in Nepal, no progress has been made in seeking product approval. This seems to have taken a back seat in the organisation's priorities and it is noted as a significant concern.

Furthermore, *collaboration* is noted as a red flag in the project. During the development of the otoscope, the lead designer was responsible for managing all relationships with end users and there was little knowledge transfer with the rest of the Field Ready team (*transparent*). It is also unclear whether there is a genuine *need* for the product in other health posts in Nepal. Indeed Field Ready found that during product development, the original health post they visited had been donated many otoscopes and no longer needed the product. This has implications for the project's *scalability*.

According to Field Ready, the innovation in this project is not in the design, but in the manufacturing process. By producing the otoscope using 3D printing it is hoped that the project can advance *local manufacture* and *local control and repair*. The design is fully modular so that it can easily maintained and repaired. One limitation is that despite the fact that the device can be printed in-country, the other parts (electronics and lenses) must still be imported. Furthermore, it is unclear who would be responsible for manufacturing the device. Recognising this problem, Field Ready have started to invest in the development of Nepal's Forum for Digital Manufacturing (FDM). The aim of the forum is to connect makers across Nepal to share knowledge and develop fabrication capacities. As well as connecting entrepreneurs, Field Ready have been actively tackling some of the challenges faced by 3D printing organisations in Nepal. Specifically, they are working on a project to develop low-cost, locally produced filament.

On one hand the project suggests a new way forward. It suggests a possible shift from away from importing goods to local manufacture, which could significantly disrupt the supply chain (*systemic*). It is also argued that the project could inspire the next generation of Nepali engineers who are interested in using new technologies to solve local problems (*empowerment*). Yet ultimately, the project does not significantly advance skills or create employment beyond the Field Ready team (*advancement*). Asides from the lead designer, Field Ready mostly rely on non-local staff.

Considering the DfSS framework (see Figure 5.6), Field Ready should prioritise quality and collaboration, and also seek to address issues related to need, advancement, transparency, local manufacture and scalability. By investing in local capacity building, Field Ready can begin to address some of these factors simultaneously. In this way, the project signals an important shift away from traditional problem-solving to capacity building.

Figure 5.6 – Evaluation of project by Field Ready – 3D printed otoscope

5.4.2 Digitally Fabricated Leg Prosthesis by BETiC at IIT-B

The Jaipur Foot is an unpatented, low-cost leg prosthesis that was first developed over fifty years ago in India. The prosthesis was developed after Dr Pramod Karan Sethi, an orthopaedic surgeon realised that many of the American and German prostheses that were being provided to patients were unsuitable. He worked with Ram Chandra Sharma, a sculptor to create a cosmetically attractive leg prosthesis. Unlike the imported prostheses, the Jaipur Foot was designed to be rugged and to allow for barefoot walking. A flexible, realistic foot was developed to accommodate a range of squatting and sitting positions that suited the Indian user (see Figure 5.7).

Figure 5.7 – The Jaipur Foot prosthesis

Ratna Nidhi Charitable Trust (RNCT) is a charitable trust in Mumbai that manufactures and distributes the Jaipur Foot prosthesis free of charge. The CEO of RNCT approached the Biomedical Engineering and Technology incubation Centre (BETiC) based at the Indian Institute of Technology-Bombay (IIT-B) to investigate how new technologies could scale-up the manufacturing process of the Jaipur Foot, to provide more beneficiaries with access to the prostheses. In partnership with google.org, the project has been exploring the potential of 3D printing and CNC milling to create a low-cost, customised socket for upper leg prostheses. As of the beginning of 2019, patient trials are being conducted to test the CNC-manufactured sockets. The CNC-manufactured socket is intended to replace the current (non-digitally fabricated) socket, which is the most technically challenging and time consuming stage of producing the prosthesis.

The new digitally fabricated socket is specifically designed to be compatible with the other parts of the prosthesis and to *complement* the existing design of the Jaipur Foot, therefore avoiding unnecessary redundancy. Throughout the project, decisions have been made to support *local manufacture, control and repair*. For example, the use of 3D scanning was ruled out, as the cost is prohibitive for scaling-up the new socket design to other trusts. The design of the socket has been carefully considered such that it can be easily produced by the existing workforce. Throughout the project, *transparency* has been important and detailed documentation has been created to facilitate local production. In this way, the *advancement* of the workforce has also been addressed.

In addition, the project promotes greater *systemic* impacts. BETiC have been advancing the Indian digital fabrication ecosystem by collaborating with Indian start-ups that are developing production tools and materials. For example, they have established a relationship with AHA 3D, an Indian manufacturer of 3D printers. By using AHA's 3D printers, they have supported the printer's development and promoted their brand. Similarly, they have collaborated with Fractal Works, another Indian based company that provides 3D printing filament. These *collaborations* reveal how this case study has cultivated an entrepreneurial ecosystem, thus triggering wider social change (*systemic*). Overall, the focus on local ownership supports the *empowerment* of users and providers.

As a whole, the project reveals a more system-focused and radical approach to social sustainability, with paradigm-related factors being considered from the start. One weakness that the DfSS framework reveals (see Figure 5.8) is that this project is primarily focused on the *needs* of the charitable trust (i.e. scaling up the production process) rather than the primary needs of the users (which include demands for more aesthetic and light weight prostheses). Furthermore, *collaboration* on the implementor side has been limited to one charitable trust, which may limit replication at other locations and present a barrier to *scalability*. In order to drive more socially sustainable outcomes, the project should address these factors (*need, collaboration* and *scalability*), and remain mindful of concerns around *access* and *quality*, which are unknown at present.

Figure 5.8 – Evaluation of project by BETiC at IIT-B – digitally fabricated socket for leg prosthesis

5.4.3 Digitally Fabricated Suction Pump Machine by FabLab/ MakerSpace Nairobi

Concern Worldwide approached FabLab Nairobi in 2013 after they recognised the potential for the makerspace to develop affordable medical devices in Kenya. They formed a partnership to develop technologies that support maternal and new born healthcare. They established a larger facility, MakerSpace Nairobi in 2016 to manage the project, and worked with Kenyatta National

Hospital to design and manufacture a low cost suction pump machine that could be manufactured in Kenya (see Figure 5.9). In 2017, The Phillips Foundation and UNICEF joined as partners.

Figure 5.9 – Design evolution of the suction pump machine developed by FabLab/MakerSpace Nairobi

The suction pump machine is a potentially life-saving device that helps to prevent the spread of infection and clear obstructions during resuscitation. The lack of available suction pumps was identified as a key challenge by the maternity ward at Kenyatta National Hospital (*need*). 3D printing has been used to manufacture the casing for the glass containers and water jet CNC cutting has been used to produce the metal casing. Clinical trials of the product are currently being conducted at Kenyatta National Hospital (*quality*).

The case study uses design to promote social sustainability across a number of criteria. The suction pump machine has been designed specifically for use in the local context, where rugged castors have replaced original castors to account for uneven flooring and the height of device is designed for the average African nurse (*suitability*). Furthermore, the machine has been designed to be suitable for a range of beneficiaries, including adults and children (*inclusive*). Features in the previously imported model of the suction pump machine have been removed to prevent misuse. For example, nurses previously pulled on the machine's wire cable to transport the device, however this has been replaced with an ergonomic handle and a detachable wire cable, which will disconnect from the device if pulled on (*usability*). So far, current estimates show that the locally manufactured machine will cost approximately 70% of the imported suction pump machine (*access*).

Local control and repair also reduces the need to import spare parts, which is a major procurement challenge for Kenyan hospitals. The product itself is highly modular, to improve the ease of repair (*adjustable*). The project has also facilitated a highly participatory process in which designers, engineers, procurement officers, hospital managers and medical professionals have been deeply engaged (*collaborative*). In addition, the makerspace have established collaborations with local manufacturers. Collaborating with influential partners is expected to support implementation at multiple healthcare facilities (*scalable*). Still, some parts are necessary to import as they cannot be sourced locally (including pressure gauges), highlighting barriers to *local manufacture* in this context.

Figure 5.10 – Kenyatta National Hospital (left), and imported suction pump machine at Kenyatta National Hospital (right)

As well as fulfilling product and process related DfSS criteria, this case study highlights the potential for more far-reaching, paradigm impacts. *Advancement* is recognised in two major ways. First, *local manufacture* of the suction pump machine offers the potential for direct job creation. Second, the project supports the development and training of local manufacturers, students and clinical staff. The Maker Project has been significantly *empowering* for participants, including the clinical staff who express a sense of ownership over the device. More importantly, it challenges the attitudes of people in Kenya towards local production and underlines the potential of local capabilities, leading to *systemic* impacts. The project itself sets precedent for manufacturing medical devices in Kenya and is aligned with broader goals set in the Kenyan government's 2018 Big Four agenda, which lists manufacturing and affordable healthcare as focus areas.

Figure 5.11 – Evaluation of FabLab/MakerSpace Nairobi – digitally fabricated suction pump machine

Reflecting on the DfSS framework (see Figure 5.11), we can see that the majority of factors have been addressed and that paradigm-related factors have been embedded throughout the project. The evaluation does however flag concerns related to *transparency*. Whilst the project has been well documented throughout, exact ownership of intellectual property is unclear due to the involvement of multiple partners at different stages in the project. There is an urgent need to address this factor to ensure the viability of the project in the future.

5.5 Discussion

This chapter has addressed concerns that social sustainability is not being adequately addressed in DF4D projects. Specifically, it has explored how design can promote social sustainability and investigated the ways in which designers can practically DfSS. Building on the theoretical foundation of DfSS established in the previous chapter, three DF4D case studies were selected for further investigation. This study led to the creation of a DfSS framework specifically for DF4D projects. The framework was also used to evaluate the case studies in order to demonstrate its value.

The empirical evidence presented in this chapter complements the findings from the DfSS literature. The DfSS framework refers to almost all of the key themes identified in the literature, however it places important emphasis on aspects that are particularly relevant to the DF4D context. Additional factors are also uncovered from the case studies that are not highlighted in the literature. Notably, the frugal attitude of designers in the DF4D context was apparent in all the interviews. This contributed to the addition of 'quality' and 'complementary' as two important factors that were not previously identified. 'Quality' refers to the need for robust, long-lasting products in the aid sector. It is perhaps not surprising that this issue is at the forefront of the practitioners' minds, given the fact it is a general area of concern in digital fabrication projects (Srai et al., 2016). 'Complementary' recognises the changing context and needs of users. It very much goes hand in hand with the calls for modular designs as part of a focus on 'adjustability'. In general, practitioners sought to avoid unnecessary waste and redundancy and to ensure that their interventions were compatible and complementary to existing solutions. In this sense the practitioners seemed to echo some of the frugal attitudes of making do with less (Radjou et al., 2012).

Asides from this, this study has helped to clarify particular dimensions of DfSS. Whereas the literature identifies 'local' as a driver of social sustainability, this study makes explicit that local ownership (through local manufacture, control and repair) is fundamental to the long-term viability of a project. The study also illuminated that DF4D practitioners felt there was a need for widespread (systems-focused and radical) change. The practitioners believed that scalability was important in driving social sustainability, and that scalable impact could go hand in hand with open source models and local manufacture. From their perspective social sustainability requires more than just isolated initiatives but compels widespread action.

5.5.1 Theoretical implications

This chapter underlines the important role of design in promoting social sustainability. Design is presented as both a source of un-sustainability and a means for achieving sustainability (Morelli, 2007; Whitely, 1993). This study expands on current knowledge on DfSS and provides a DfSS framework, specifically aimed at designers/practitioners working on DF4D projects. By focusing on social sustainability, it attempts to address the limited research in this area. Nonetheless, it acknowledges perspectives that economic, environmental and social dimensions are inherently related and interdependent (Zink, 2014). In developing the DfSS framework, it is suggested that designers *begin* by examining the social dimension of sustainability (Boyer et al., 2016), and then consider the implications on economic and environmental dimensions. This feedback can be used to continuously adjust decision making in the design process, until an optimum scenario is reached for sustainability as a whole. This offers an alternative to the current "win-win" logic, which positions economic, social and environmental aspects of sustainability as equal, but in practice maximises economic benefits (Montabon et al., 2016).

Within the DfSS framework, product, process and paradigm factors are presented as three necessary dimensions that must be fulfilled to achieve social sustainability. The identification of product factors builds on existing approaches to Design for Sustainability that focus on quality, usability, durability and inclusive design (Bhamra & Lofthouse, 2007). Central to much of this dialogue is the increasing focus on user needs (Margolin & Margolin, 2002; Melles et al., 2011; A. Thomas, 2006) which are recognised as being contextual and situated (Bezerra & Brasell-Jones, 2005; Stairs, 2005). This leads to the process factors which confirm arguments in the previous chapter that DfSS is participatory (Bjögvinsson et al., 2012; Hillgren et al., 2011; Manzini & Rizzo, 2011), democratic (R. C. Smith & Iversen, 2018; Thorpe & Gamman, 2011), and cultivates local ownership (Caruso & Frankel, 2010; Kang, 2016). Finally, the paradigm factors complement theories on agency and postcolonialism, which suggest that imported technologies increase dependency on aid and undermine local knowledge (Ö. Er & Kaya, 2008; Kapoor, 2008). In contrast, this framework advocates for the development of local capabilities, which empower people to develop and own solutions. Whilst Design for Sustainability has mainly focused on product factors and to some extent process factors, the framework highlights that DfSS demands equal attention to be given to product, process and paradigm factors. To put it simply, social sustainability cannot exist without addressing all three dimensions.

It is argued that the integration of these three dimensions marks a shift towards more systems-focused DfSS. Systems design recognises the complex, interrelated nature of the world. Notably, systems design draws attention to desired outcomes and goals, rather than specific products or technologies (Blizzard & Klotz, 2012). Similarly, in the DfSS framework it is suggested that the inclusion of product, process and paradigm factors allows designers to work towards the broader goal of sustainable development. The DfSS framework specifically encourages designers to create solutions that are not just user-focused but are systems-focused. Rather than focusing on how products can solve people's needs, the findings draw attention to how the entire project lifecycle (including design, manufacture, use and maintenance) can maximise social sustainability. Design then is not simply about the physical creation of products and structures, but is rather positioned as an approach to enquiry.

Drawing on theory from innovation and technology studies, it is argued that the inclusion of product, process and paradigm factors creates the possibility for more radical DfSS. According to Freeman & Perez (1988), radical solutions often combine product, process and organisational innovations. Radical solutions can also trigger new markets, which in the context of DF4D could be the demand for locally designed products. Geels & Schot (2007) explains that radical solutions provide an opportunity to challenge the status quo. Therefore, solutions that challenge traditional models of aid in favour of advancement, empowerment and systemic change necessitate radical solutions. Overall, these findings suggest that strong sustainability must address the underlying causes of un-sustainability (Melles et al., 2011). Simply, incremental solutions will not suffice, and wide-scale change should be embedded within ambitions for social sustainability (Savaget et al., 2019).

5.5.2 Practical implications

For practitioners working on DF4D projects, the DfSS framework provides useful guidelines for planning and assessing projects. Instead of just focussing on product performance factors, it encourages designers to look more broadly at how the entire product lifecycle can maximise social sustainability. Overall, this shifts thinking away from short-term to long-term goals.

To assess the value of the DfSS framework it was shown to the organisations in this case study for their feedback. The case studies were also discussed with practitioners, highlighting its potential for stimulating reflection. Their feedback confirmed the potential value of the framework, during the planning and evaluation stages of the design process. The practitioners explained how the framework would improve their current practice and how they would do things differently. Specifically, they believed that the framework would encourage them to think about the broader impacts of their interventions and to avoid a narrow product focus. Furthermore, they felt that the framework would help them to identify areas that had been overlooked in ongoing projects.

> *"Engineers want to fix the engineering problem. They normally fix what they can fix rather than looking at the wider scope and thinking about the value of fixing that thing. Say in a hospital this could help them to think about what the most valuable thing is to the health care practitioner rather than 'here is a broken fuse, let me fix it'."* (Innovation Advisor, Case Study 1)

The organisations were interested in using the framework in their future projects. The framework in this study has provided a valuable underlying model, that could be further developed into a tool. A tool aims to satisfy a particular outcome and is based on an underlying conceptual model (Blessing & Chakrabarti, 2009). It is normally iteratively developed based on testing and evaluation of its utility and usability (Eckert et al., 2003). Whilst this is outside of the scope of this thesis, it is certainly a possible future direction for the research.

> *"I can see us using this, I can see this framework having some great utility… One of the things that we often struggle with is how to prioritise projects... this could help… It intuitively makes sense at the start of the design process, but it would also provide a useful check at the end." (Innovation Lead, Case Study 1)*

"I think you have captured some of the most important criteria... I can see this being used as a sustainable design version of the business canvas tool." (Project lead and engineer, Case Study 2)

"I think this framework is really useful. It captures all the aspects that we encourage students to think about during hackathons... We definitely could use this to help plan projects." (Makerspace manager and designer, Case Study 3)

5.6 Reflections on the findings

This chapter has advanced our understanding of DfSS, by developing a practical framework that is explicitly intended for use in DF4D projects. The DfSS framework identifies a set of factors that must be addressed to fulfil social sustainability. It provides a tangible way of engaging with the nebulous concept of social sustainability by offering a view of what it might look like in DF4D projects. It therefore satisfies concerns that current definitions do not account for different realities at the local-level. This study has also drawn on theory from systems design and innovation to suggest that social sustainability necessitates a shift from user-related to systems-related, and from incremental to radical solutions.

The DfSS framework presented in this chapter is the logical result of the research methods selected. In the previous chapter, thematic analysis was selected to identify the key themes of DfSS within the literature. These were iteratively grouped in categories of conceptually similar themes. In this chapter, multiple case studies were conducted to further investigate the key themes of DfSS in the DF4D context. Several cycles of coding the data and thematically analysing the findings led to the identification of sixteen factors. From the outset, the aim of this chapter was to provide an accessible framework to support designers to DfSS in DF4D. This set some expectations of what the final framework might look like. Furthermore, the process of developing the framework from coding the literature and case study data, naturally meant that the framework would result in a set of factors.

Referring to the pragmatist paradigm outlined in Chapter 2, it was asked at the start of the research: what difference would it make to do the research one way rather than another? This question ultimately led to the decision to investigate DfSS in DF4D from two different perspectives. Whereas this chapter has focused on an analytical approach, the subsequent chapter takes a critical systems approach to investigate DF4D projects. Whereas the former seeks simplicity, the latter requires an acceptance of complexity. In this thesis it is put forward that both approaches are independent but complementary in their investigation of socio-technical systems.

5.7 Summary

This chapter has responded to the problem that designers lack practical support to DfSS in DF4D projects. Building on the theoretical foundation of DfSS established in the previous chapter, three case studies of DF4D projects were conducted to develop a contextually relevant understanding of DfSS in DF4D. This study has focused on the development of a DfSS framework that provides guidelines for practitioners to help plan and evaluate DF4D projects. Each of the case studies were evaluated using the framework to demonstrate its value. The findings contribute to our theoretical understanding of DfSS by revealing how design can trigger social sustainability at product, process and paradigm levels. Specifically this study highlights the potential for DF4D to create more radical, systems-focused social sustainability. The chapter concluded by explaining that the DfSS in DF4D framework represents a sets of factors and is the logical outcome of the analytical approach taken in this chapter. Referring to the pragmatist position that different methods seek different outcomes, it suggests that a critical systems approach would provide an independent but complementary investigation of DfSS in DF4D. The following chapter is dedicated to this perspective and aims to further enrich our understanding of DfSS in DF4D.

Chapter 6 A critical systems approach to DfSS in DF4D

6.1 Introduction

At the start of this thesis it was put forward that there are many different ways of looking at the same problem, and that different perspectives will naturally elicit different understandings of the same phenomenon. The previous chapter took an analytical approach to develop a framework to support DfSS in DF4D. Although the findings highlighted the importance of systems-focused design, the study itself was methodologically rooted in a reductionist approach. Whilst the former chapter focused on breaking down complexity into components, this chapter embraces complexity by adopting a critical systems approach. It pays particular attention to the findings in Chapter 4 that DfSS necessitates a participatory design practice. It presents Designet, a participatory visual toolkit that allows actors to map the networks of their own DF4D projects. It documents the use of Designet to map the networks of the three case studies identified in Chapter 5. It also analyses the networks of these case studies to reveal new insights for DfSS.

Section 6.2 explains how a critical systems approach can complement analytical thinking. It presents DF4D projects as complex socio-technical systems and, argues that it is impossible to understand these complex systems without developing a deep understanding of the networks that underlie them. Section 6.3 reflects on the convergence of network analysis and design research. It identifies Actor Network Theory (ANT) as a popular approach in this domain and introduces some key network concepts. Section 6.4 explores a designerly approach to mapping networks. Section 6.5 describes the development of Designet, an initial toolkit for mapping the networks of DF4D projects. Section 6.6 explains how Designet was used to collect data about the DF4D projects in this study. Section 6.7 reflects on the perceived value of Designet. Section 6.8 documents the methods used to analyse the networks of the DF4D projects. Section 6.9 describes the networks of the case studies in detail. Finally, Section 6.10 summarises the main findings and tackles the limitations of this study.

6.2 Why is a critical systems approach needed?

> *"I don't think the systems way of seeing is better than the reductionist way of thinking. I think it's complementary and therefore revealing." (Meadows, 2008, p. 6)*

Since the Industrial Revolution, the scientific method has been the predominant way of approaching complex problems (Meadows, 2008, p. 4). This analytical approach aims to reduce complexity by focusing on the individual parts of a problem. In the previous chapter, this approach was successfully used to develop a DfSS framework for DF4D projects. Whilst analytical thinking is useful for deriving operational variables, it has been also criticised for not paying enough attention to the interconnected relationships between different elements (Sayer, 2010). In Chapter 4, it was put forward that DfSS necessitates a more participatory, equitable and connected design practice in which actors have local agency. In this chapter, a critical systems approach provides a complementary lens with which to better understand these aspects of DfSS.

At its heart, a systems approach is based on the idea of holism in which "*the whole is more than the sum of the parts*" (Koffka, 1991, p. 173). It recognises the deeply interconnected nature of the world around us, and aims to understand the relationships that hold these complex systems together (Sterman, 2000, p. 4). Critical systems thinking emerged in the 1980s in pursuit of more emancipatory paradigms of knowledge (Flood, 1990; M. C. Jackson, 1991; Ulrich, 1983). It specifically aimed to promote the voice of actors who are directly affected by a system's outcomes (Jackson, 1991). In an effort to achieve this it adopts a pragmatic position which recognises the importance of both 'soft' qualitative and 'hard' quantitative ways of thinking. Its underlying emancipatory interest means that it is a useful perspective with which to frame the concerns of DF4D projects.

6.2.1 What can we learn from studying the networks of complex socio-technical systems?

"We are surrounded by systems that are hopelessly complicated" (Barabási, 2016)

The concept of the socio-technical system was established in the late 1950s in the field of labour studies by the Tavistock Institute in London (Trist, 1981). Whereas prior to this technology was largely viewed as being independent from social systems, the concept of the socio-technical system established a reciprocal relationship between humans and technologies (Ropohl, 1999). In a socio-technical system, the purpose of the technical and social systems are deeply intertwined; they cannot work on their own but through the involvement of human actors (Geels, 2004). More precisely, a socio-technical system represents the "*linkages and the alignment of heterogenous, social, and technical elements into working configurations"* (A. Smith & Stirling, 2010). It is clear then that any DF4D project can be viewed as a socio-technical system.

These systems can also be described as complex, because they involve many interconnected elements that are arranged in constantly changing ways (Saurin & Gonzalez, 2013). The overall behaviour of these systems can be difficult to predict and manage because the exact relationships within them are difficult to describe and understand (Reymondet, 2016). A popular way of dealing with complex systems is to develop a deep understanding of the networks behind them (Barabási, 2016). Network analysis provides a useful tool for understanding the interactions between different systems elements (ibid). It posits that any cause, effect or association between elements can be conceptualised as a network (Brandes et al., 2013).

There is a long history of studying networks in graph theory (Sylvester, 1878) and sociology (Moreno, 1953). Early sociologists such as Emile Durkheim and Ferdinand Tonnies provided a theoretical grounding to the field, arguing that focussing on the actions of individuals did not provide adequate explanation for social phenomena. Instead, they were interested in collections of individuals that resulted from direct and indirect social ties. Although research on networks fell out of popularity in the mid 20^{th} century, interest in the field has started to grow exponentially in the past two decades (Easley & Kleinberg, 2010; Newman, 2010). In part, this has been driven by the emergence of network science, a discipline that has applied mathematical formalism to the study of networks (Barabási, 2016).

In recent years, network analysis has been used in a wide range of disciplines, including biology, electrical engineering, economics, ecology, public health and sociology (ibid). Specific applications have varied from modelling the impact of the internet (Otte & Rousseau, 2002) to forecasting epidemics (Ortiz-Pelaez et al., 2006) to mapping neurons in the brain (Sporns, 2002). A broad application of network analysis is possible because it is not a predictive theory that defines propositions or correlations but it is rather a method or "*a loose federation of approaches*" (Burt, 1980, in Emirbayer & Goodwin, 1994) that is used to understand a network's structure and its outcomes (M. Zhang, 2010).

Within the field of innovation studies, network analysis has become a popular tool to study both organisations and processes (Coulon, 2005). These domains can be referred to respectively as 'networks of innovators' (Powell & Grodal, 2004) and 'networks of innovation' (Tuomi, 2002). Whereas the former focuses explicitly on social systems, the latter considers the heterogeneous integration of people and technologies as part of a socio-technical system. Many studies have been dedicated to studying 'networks of innovators' and there is an extensive body of literature on Social Network Analysis (Borgatti et al., 2009; Scott, 1988). Instead this thesis focuses on 'networks of innovation' by firmly positioning DF4D projects as socio-technical systems. This chapter introduces network analysis as a means to analyse DF4D projects and to draw theoretical conclusions about DfSS from such research.

6.3 How has network analysis and design research converged?

Product development involves the interaction of people, technologies and artefacts simultaneously (M. Perry & Sanderson, 1998). Traditionally design research has concentrated on the role of artefacts (Bucciarelli, 1995) but neglected the role of social interactions. This had led to calls for a more holistic approach to design that unifies the study of social interactions and the production of artefacts (Papalambros, 2015).

Network analysis offers a potential solution to this problem, and in recent years researchers have begun to explore how it might provide insights on design and product development (Piccolo et al., 2019). Within the field of engineering design, network analysis has been used to analyse the complexity of modern engineering projects. For example, Batallas & Yassine (2006) use network analysis to analyse information exchange in the product development of an aircraft engine. Many other authors have used Design Mapping Matrices (DSMs) (Danilovic & Browning, 2007) or Design Structure Matrices (DSMs) (Browning, 2016; Collins et al., 2009) to represent the interactions within the design process.

Within design research, several authors have highlighted the value of visualising networks. Ceschin (2012) creates a tool to help designers visualise the actors and social groups that influence projects. Baek et al. (2015) visualises the networks of a farmers' market in Milan to investigate community resilience. Aranda-Jan (2018) conceptualises the design context as an actor-network in the study of medical devices in the Global South. In this domain, Actor-Network Theory (ANT) is a particularly popular network approach. Yaneva (2009) explores how ANT can be used to investigate everyday design culture and practices; Potts (2009) uses ANT to analyse interactions with multimedia interfaces; Andersen et al. (2015) apply ANT as a conceptual framework to analyse participation in the design process; Palmås & von Busch (2015) also consider how ANT can explain how the goals of actors 'drift' in participatory design. On the whole, design research tends to focus on specific conceptual elements of ANT or to integrate mainstream network analysis methods into ANT studies. This can partly be explained by the absence of prescriptive methods in ANT, which has led to a lack of consensus on which methods are appropriate (Özman, 2017). The following section will provide a more detailed overview of ANT.

6.3.1 What is Actor-Network Theory (ANT)?

ANT is a post-structuralist perspective that was initially developed by Michel Callon, Bruno Latour and Johnson Law to deal with socio-technical 'imbroglios' (Latour, 1994). ANT handles the social-technical divide by rejecting the idea that purely technical or social relations are possible (Law, 1992). Instead, networks are conceptualised as the "*tracing of associations*" between heterogeneous elements (Latour, 2005, p. 5); the world is full of hybrid entities in which objects are given the status of "*participants in the course of action*" (Latour, 2005, p. 70). That is not to say that human and non-human actors are the same, but that their effects are comparable (Latour, 2005 p. 76). It is through these interactions of different human and non-human actors that meaning is constructed (Latour, 2005 p. 39).

Although the treatment of human and non-human actors within a 'flat' ontology has been the subject of controversy in sociology (Winner, 1993), design research has a long history of studying the ability of artefacts to influence interaction (Norman, 2002). For example, Gibson's (1979) concept of affordances establishes that objects can compel certain actions[9]. Artefacts are also treated as a communicative resource that can induce changes in human practice (Crilly et al., 2004, 2008; M. Perry & Sanderson, 1998). It is perhaps not surprising then, that ANT is particularly popular among design researchers.

ANT is largely critical of the 'social force' model which prevails in the social sciences. It argues that attempts to explain the causes of phenomena using social forces (e.g. power, the markets) fail to unpack their constituent parts and the networks that constitute them.

> *"Once new associations have been stocked in the package of social forces, there is no way to inspect their content, to check their expiration dates, to verify if they really possess the vehicles and the energy to be transported all the way to what they claim to explain."* (Latour, 2005 p. 248)

Another key concern of ANT is the uncovering of conflicting accounts or controversies. When Bruno Latour was asked to explain exactly how to map networks, he simply replied "*just look at the controversies and tell what you see*" (Venturini, 2010). Although this response might seem flippant it underlines a key tenet of ANT. According to Latour, controversies are fundamental parts of networks that allow for the exploration of problems that might otherwise remain hidden.

ANT also squarely faces criticisms about structural determinism. Instead of concentrating on how the patterns of relationships affect the network's behaviour, ANT shifts the focus back to the individual actors in the network (Coulon, 2005; Özman, 2017). ANT shows that individual actors do hold agency[10], arguing that a system's behaviour is just the result of the momentary interactions between actors in the network.

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[9] The affordance of an object specifies a range of possible activities that might be taken. *"The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment."* (Gibson, 1979 p. 127)

[10] Agency refers to an actors ability to act independently, without being constrained by structural factors that limit their actions (Emirbayer & Mische, 1998). ANT offers a post-structuralist perspective in that it pays attention to the individual difference of actors and their capacity to act (Coulon, 2005). Structuralism on the other hand, puts forward

> *"Power, like society, is the result of a process and not a reservoir, a stock or a capital... Power and domination have to be produced, made up, composed. Asymmetries exist, yes but where do they from and what are they made out of?"* (Latour, 2005 p. 64)

A necessary point of clarification is that ANT is not a theory in the sense it does not predict outcomes, but it rather advocates a loose set of methods that suggest a different way of studying social phenomena. Latour describes it simply as a theory "*about how to study things or rather how not to study them*" (Latour, 2005 p. 142).

In this study, ANT offers a valuable methodological starting point for investigating DF4D projects. First, its consideration of human and non-human actors provides a useful lens to explore these complex socio-technical systems. Second, ANT's emphasis on unpacking power and agency means it is well placed to investigate concerns about participation, influence and connectedness in DfSS. Third, the concept of controversies provides a way to investigate potentially conflicting accounts to help identify issues that may affect social sustainability.

6.3.2 Some important network concepts

At this point it would be useful to pause to introduce some basic network concepts. Table 6.1 describes the key terminology in mainstream network analysis and ANT. The fact that these definitions are rather circular underlines the reality that the existence of an actor necessitates the network and visa-versa. According to ANT, actors are always the result and the constituent parts of networks (Latour, 2005, p. 63).

This study deals with heterogeneous networks, which means that the networks are composed of different types of actors or nodes. In this thesis, the terms 'actor' and 'node' are used synonymously. The connections between actors are referred to as 'associations' or 'edges' interchangeably. These associations can be weighted to represent the significance of a particular relationship. For example, the weight of an association could represent the time that two people spend talking on the phone (Barabási, 2016, p. 54). Associations can also be directed or undirected. For example, a phone call is an example of a directed link, in which one person calls

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that it is only the structure itself that constrains or allows action, therefore undermining the individual agency of actors (Emirbayer & Goodwin, 1994).

another. A friendship or romantic relationship is an example of an undirected link (Barabási, 2016, p. 46).

Table 6.1 – Key terminology in network analysis and ANT

Network analysis	ANT	Description
Network	Network	A connected set of nodes/actors.
Node	Actor	The basic elements of a network.
Edge	Associations	Connections between two nodes/actors. They can be unweighted or weighted, directed or undirected.

6.4 A designerly approach to mapping networks

The majority of studies collect data about networks using interviews and surveys (R. E. Freeman, 2004). However these static approaches are often difficult and burdensome for respondents and researchers (Marin & Wellman, 2014). Many authors report that the process is lengthy and tedious, and can result in incomplete representations because of 'informant exhaustion' (D. C. Bell et al., 2007; Marsden, 2005; White & Watkins, 2000). These approaches also tend to silo perspectives so it can be difficult to manage conflicting accounts (Marin & Wellman, 2014).

As an alternative, visual artefacts have a long history in design of being used to elicit engagement and to support the meaningful participation of multiple stakeholders (Eriksen et al., 2014; Miettinen & Virkkunen, 2005; Morrison & Dearden, 2013; Muller & Kuhn, 1993). They are also a popular way of dealing with sustainability challenges. For example, Hyysalo et al. (2019) developed a mid-term range pathway creation toolset for managing sustainable transitions; Dusch et al. (2010) developed a sustainable design toolkit and; and, Schiffer (2007) developed *net-map*, a participatory toolkit to visualise the relationships and power dynamics within projects.

The urgency for more designerly ways of mapping networks is noted by Latour (2008) in his keynote speech to the Design History Society. He ends his talk with a strong call to action, inviting the design community to find new ways of representing networks.

> *"In its long history, design practice has done a marvellous job of inventing the practical skills for drawing objects… but what has always been missing from those marvellous drawings…*

are an impression of the controversies and the many contradicting stakeholders that are born within these… where are the visualization tools that allow the contradictory and controversial nature of matters of concern to be represented?" (Latour, 2008)

Reflecting on this, Storni (2015) builds a case for a methodological turn in design in which the designer assumes the role of a mapmaker. The mapmaker helps to visualise the design process and communicates it with the public. In a similar vein, Venturini (2010, 2012) and Venturini et al. (2017) introduce the designer as a social cartographer, someone who explores potential conflicts and supports actors to construct their own network maps. He specifically explores the use of digital tools for representing actor-networks. He proposes that actors should be given the opportunity to describe the world in their own ways and that multiple actors should be included in the process to "*construct a shared cosmos*". This view echoes Latour's call to "*let the actors have some room to express themselves*" (Latour, 2005 p. 142).

Venturini (2012) also argues that mapping should not just be constrained to actions and relations, but should also consider the specific meanings associated with particular interactions. Thus visual tools should be flexible and dynamic to meet local needs. De Moor (2018) takes this further to advocate for a network mapping technique that can be adapted and owned by the community themselves. Whilst a common set of visual tools can help to establish common ground, he argues that the community should be able to help define these tools. He highlights the necessity of constraining the mapping process *just enough*:

"*On one hand, community networks should be able to name their own customary types of elements and connections, on the other hand, there is a growing body of knowledge about the general kind of things that often seem to matter in typical cases… [and the need to avoid] the often observed trial and error of communities ad hoc trying to map their world without knowing what to map and what to leave out, getting lost in their map, and giving up*." (De Moor, 2018)

A final precaution is added by Venturini (2012) who advocates that the so-called 'social cartographer' should seek to create multiple maps and expect redundancy. Each map can be dedicated to a specific part of the phenomenon and redundancy provides validation of reality.

Based on the recommendations for mapping networks found in Venturini (2010, 2012), Venturini et al. (2017), and De Moor (2018), the following recommendations for mapping the networks of DF4D projects are suggested.

1. Mapping should explore issues related to social sustainability.
2. Mapping should be led by the actors who are directly affected by the system outcomes.
3. Mapping should encourage participation.
4. Mapping should explore different perspectives.
5. Mapping should be flexible and suitable for the local context.
6. Mapping should aim to mitigate complexity.
7. Mapping should support story-telling and sensemaking[11].

6.5 Developing a designerly toolkit to map the networks of DF4D projects

Given the popularity of visual artefacts in design research and the need for more designerly ways of mapping networks, the researcher began to explore how a toolkit might help to collect data about the networks of DF4D projects. Taking a critical systems approach, the researcher also wondered whether such a toolkit could help to emancipate participants by "*making the whole environment more favourable to an unspecified variety of encounters, conversations, and actors*" (Manzini, 2019, p. 29). In other words, the researcher wanted to explore how a toolkit could create a space for meaningful encounters between different stakeholders, to take steps towards social sustainability. From this perspective, the toolkit could not only serve as a means for data collection but could also act as a 'boundary object' in its own right, a temporary bridge to create shared meaning and facilitate communication (Star & Griesemer, 1989).

[11] Sensemaking is the process by which people give meaning to their shared experiences. Weick et al. (2005) define it as "*the ongoing retrospective development of plausible images that rationalize what people are doing*". Klein et al. (2006) describe it as the *"motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively".*

To begin with, a set of requirements was identified for a toolkit according to the recommendations for mapping the networks of DF4D projects (see Table 6.2). Based on these initial requirements, Designet was conceived of as a participatory toolkit that could enable stakeholders to map the networks of their own DF4D projects. The following section will describe the development of Designet in more detail. It is important to note that any reference to Designet as a toolkit does not imply that it is a fully validated tool. Tool development is a lengthy and iterative process that typically involves several stages of testing (Moultrie, 2004). This study aims to develop an *initial proposal* for a toolkit, that is primarily used in this chapter for collecting data about the networks of the main case studies.

Table 6.2 – Requirements for toolkit for mapping the networks of DF4D projects

Mapping should …	**Toolkit should…**
1. Explore issues related to social sustainability	– Create a space for reflection on current and future practices
2. Be led by the actors who are directly affected by the system outcomes	– Be easy to understand and use – Be adapted according to participants' preferences
3. Encourage participation	– Be intuitive and low-tech – Provide an engaging set of visual aids – Not be too time consuming to use
4. Explore different perspectives	– Allow for easy editing and map refinement
5. Be flexible and suitable for the local context	– Be easily customised by the participants
6. Mitigate complexity	– Include a basic ontology of actors and associations to prompt participation
7. Support story-telling and sensemaking	– Encourage participants to 'think out loud' – Assign different values for connections

6.5.1 Defining a basic ontology for the toolkit

Earlier it was put forward that Designet could act as a boundary object: "*plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites*" (Star & Griesemer, 1989, p. 393). To help guide participation, it was decided to define a basic ontology that could be adapted and expanded on by the participants. In simple terms, an ontology is a set of concepts that helps to build knowledge.

6.5.1.1 Actors

It is widely believed that product development consists of multiple interconnections between different elements including people, technologies, artefacts and the wider context (Piccolo et al., 2018). Based on these well-known elements, four categories of actors were defined: people, technology and tools, things[12], and places. In an effort to identify actor types within these four categories that reflected the reality of DF4D, it was decided to review the interviews in the exploratory case study (in Chapter 3). All the interviews were carefully analysed and any human or non-human actor mentioned was recorded. This resulted in a list of actor types involved in DF4D projects (see Table 6.3).

Table 6.3 – Actor categories, types and descriptions

Actor category	Actor category description	Actor types	Actor type description
People	Human actors involved in the design process	Beneficiary	Person who benefits from using the product
		Designer	Person responsible for product development
		Donor	Individual or organisation that provides funding
		End user	Person who uses the final product
		Government	Local, national or international government
		Implementor	Individual or organisation responsible for product implementation
		Influencer	Individual or organisation that influences the project
		Initiator	Individual or organisation that initiates the project
		Maker	Person responsible for producing the prototype or final product
		Material supplier	Individual or organisation that provides raw materials
		Partner	Organisational partners e.g. NGOs
		Volunteer	e.g. interns, temporary staff
Technology and tools	Physical/ digital infrastructure and	Digital design tool	e.g. CAD, other digital software
		Digital fabrication tool	e.g. 3D printer, laser cutter, CNC mill

[12] Things was chosen in response to calls to dismantle the black-box of designing 'objects' (Binder et al., 2011). 'Things' supports more open-ended and unfinished representations (Storni, 2015).

	machinery that produce things	Hand tools	non-digital, non-powered hand tools e.g. hammer
		Non-digital fabrication tools	Non-digital, powered tools e.g. lathe, drill
		Technology platforms	Technology platform that supports use of design and fabrication tools e.g. thingiverse, online forums
Things	Artefacts created in the design process	Design sketches and models	Any design sketches and models produced during project
		Document	e.g. reports, design briefs, need assessments
		Prototype	Work in progress
		Finished product	Physical outcome
Places	Locations in which the design process takes place	Design context	Where conceptual design happens
		Product context	Where product is made
		Use context	Where the product is used

6.5.1.2 Associations

Interactions between actors in the network are often conceptualised as flows of resources (Özman, 2017). These resources can be physical e.g. money or materials, or intangible e.g. information and knowledge (Ehrenfeld, 2008, p. 81). Throughout the design process these resources are constantly being transferred to or from different actors. In addition to these resources, is the flow of values e.g. trust, respect and care (Graeber, 2001). In Graeber's view values are not something that people have, but rather values emerge in action. This processual conceptualisation follows a similar logic to ANT's argument that social forces are not 'reservoirs' or 'stocks', but they are manifested through the interactions of a network (Latour, 2005 p. 64). As Graeber describes:

> *"It is the process by which a person's invisible "potency" – their capacity to act – is transformed into concrete perceptible forms… If one gives another person food and receives a shell in return, it is not the value of the food that returns to one in the form of the shell, but rather the value of the act of giving it."* (Graeber, 2001 p. 45)

According to Graber (2001 p. 47) values signify the importance of actions, echoing Venturini's (2010) earlier emphasis on story-telling, which argued that mapping the network should not be *"limited to the statements, actions and relations, but has to extend to the meaning that actors attribute to them"*.

In light of this, five types of association were defined: money, materials, knowledge, information and intangible values. These edge types were cross-checked with the interviews in the exploratory study. Particular attention was paid to how the practitioners in the explorary interviews described the interactions between different actors in DF4D projects. These associations were recorded as: information, intangible values, knowledge, materials and money. It was decided that these types of association were sufficient to describe the various interactions in DF4D projects. Table 6.4 provides a description of each of these categories.

Table 6.4 – Association types and descriptions

Association type	**Description**
Information	Facts about someone or something; data
Intangible values	Relational values e.g. trust, friendship, respect, care
Knowledge	Understanding based on skill, experience; practical or theoretical understanding
Materials	Physical resources e.g. raw materials, production tools, prototypes
Money	Financial resources

6.5.2 Developing the toolkit

The Designet toolkit and workshop were designed simultaneously based on the requirements established earlier. First, to encourage participants to explore controversies and to revise their networks, it was decided that they should be mapped on whiteboard paper. The whiteboard paper could be easily laid out on a table or flat surface. This low-tech approach would allow participants to construct their own networks, and make quick edits and adjustments. It would also encourage participants to re-work their networks, providing an opportunity to explore potentially conflicting versions.

Second, it was decided that the networks should be both directed and weighted, to capture the most detailed visualisations possible. This would allow participants to indicate the strength of a particular relationship and which actor was performing a particular action. It was decided that participants could draw arrowed-lines between nodes to show the direction of the connections. They could use a solid line to indicate a strong connection and a dashed line to indicate a weak connection.

Third, in order to balance the need for flexibility and simplicity, it was decided to create a customisable set of cards (4cm x 4cm) to represent the actors defined in the previous section.

These cards were designed using Adobe Illustrator and open source icons available from www.flaticon.com[13]. The cards were printed and laminated so that they could be written on using whiteboard markers and easily reused for subsequent workshops.

Each of the cards included: a description of the actor type (e.g. designer, donor, digital fabrication tool); an icon to visualise the actor type; and, a space for participants to describe the actor (e.g. Mr S, Organisation A, Makerbot 3D printer). The cards were colour coded to indicate which actor category they belonged to (e.g. people, technology and tools etc.) (see Figure 6.1). In addition, several blank cards (with no actor type) were created to allow participants to define the actors themselves, using language that they felt was appropriate. To represent the different types of edges, circular counters (1.5 cm diameter) were designed for each of the five different types of associations (see Figure 6.2). These counters could easily be added to the connections drawn on the networks to articulate the nature of the associations between the actors (see Figure 6.3 for an example section of a network map). In addition, 'challenge counters' (1.5 cm diameter) were also created so that participants could easily indicate challenging interactions or aspects of the network. Figure 6.4 shows the complete contents of the Designet toolkit.

In order to develop the toolkit, a co-creation workshop was run in March 2018 with three colleagues from the Institute for Manufacturing, University of Cambridge (Clara Aranda-Jan, Davor Copic and Naoum Tsolakis), who were selected based on their experience in design and/or network analysis. The purpose of the workshop was explained to these participants and they were given some background about a hypothetical project, a 3D printed spare part for a suction pump machine, which was based on a project in the exploratory case studies. The participants attempted to map the project using the toolkit, and their reflections and feedback on the process was noted throughout. The workshop confirmed that the look and feel of the toolkit was appealing and intuitive for people to use. The cards and counters seemed to encourage people to work quickly. However, there was some initial confusion about how to begin mapping, or in which order the mapping should be completed. It was clear that the participants needed more structure to help mapping. There were also lots of clarification questions about what particular cards meant.

[13] All the icons are fully credited in Appendix Table 3.

Following this co-creation workshop it was decided to create a visual glossary to explain each of the actor types (see Figure 6.5). It was also decided to scaffold participation by mapping each part of the design process in turn. Seven stages of the design process were defined based on Pugh (1991) and the British Design Council (2005) (define, design, test, produce, implement, adopt, sustain). To help organise the placement of the actor cards, horizontal lanes for each actor category were defined. Figure 6.6 shows the template used for mapping the design process. On the vertical axis are each of the actor categories and on the horizontal axis are the project stages. For example, all the people involved in the define stage are placed in the first row and first column, all the technologies and tools involved in the define stage are places in the second row and first column, and so on.

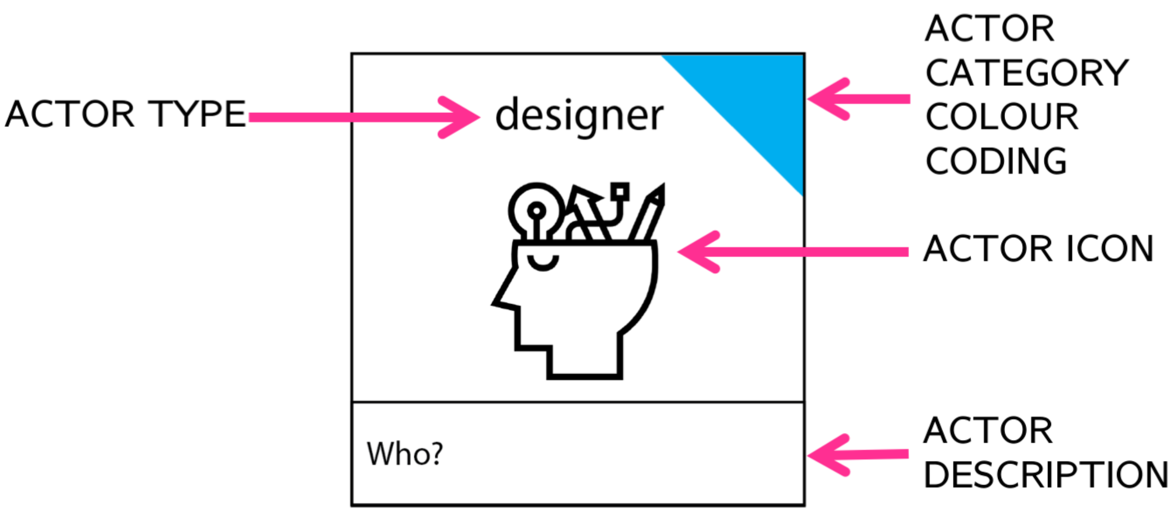


Figure 6.1 – Example actor card

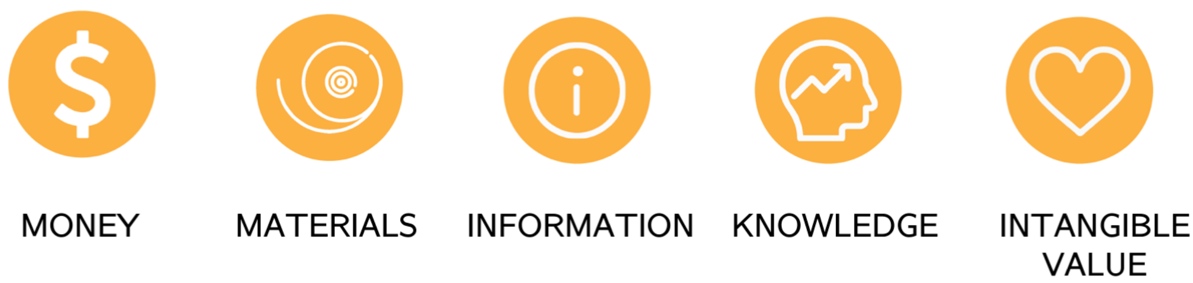


Figure 6.2 – Association counters

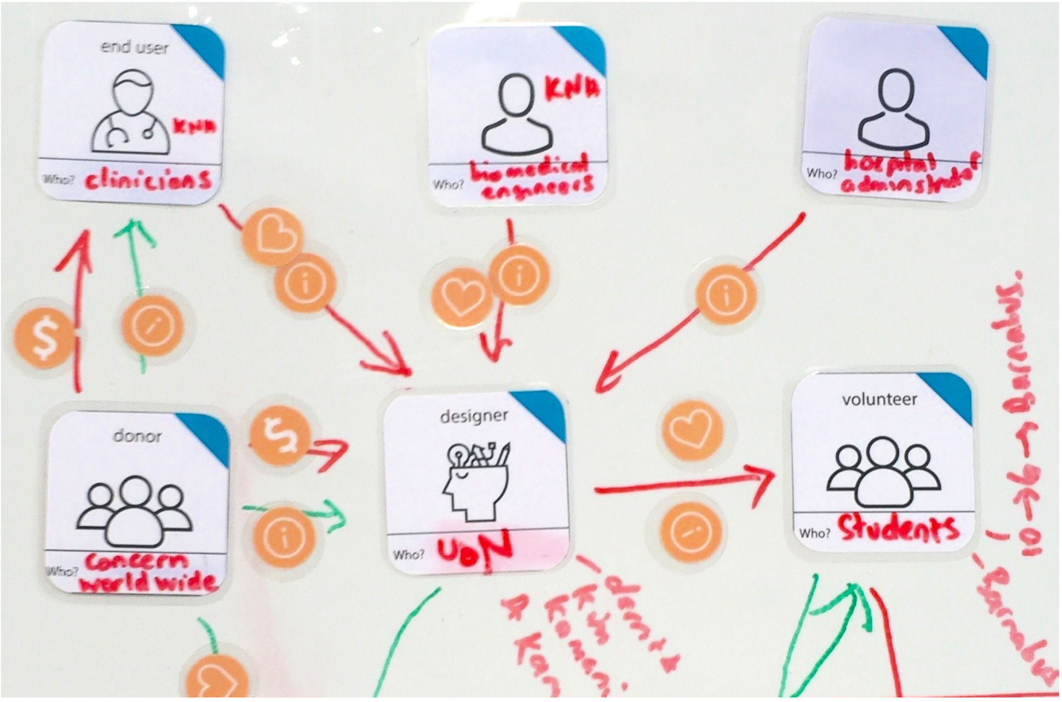


Figure 6.3 – Example section of a network map to show the use of actor cards and association counters

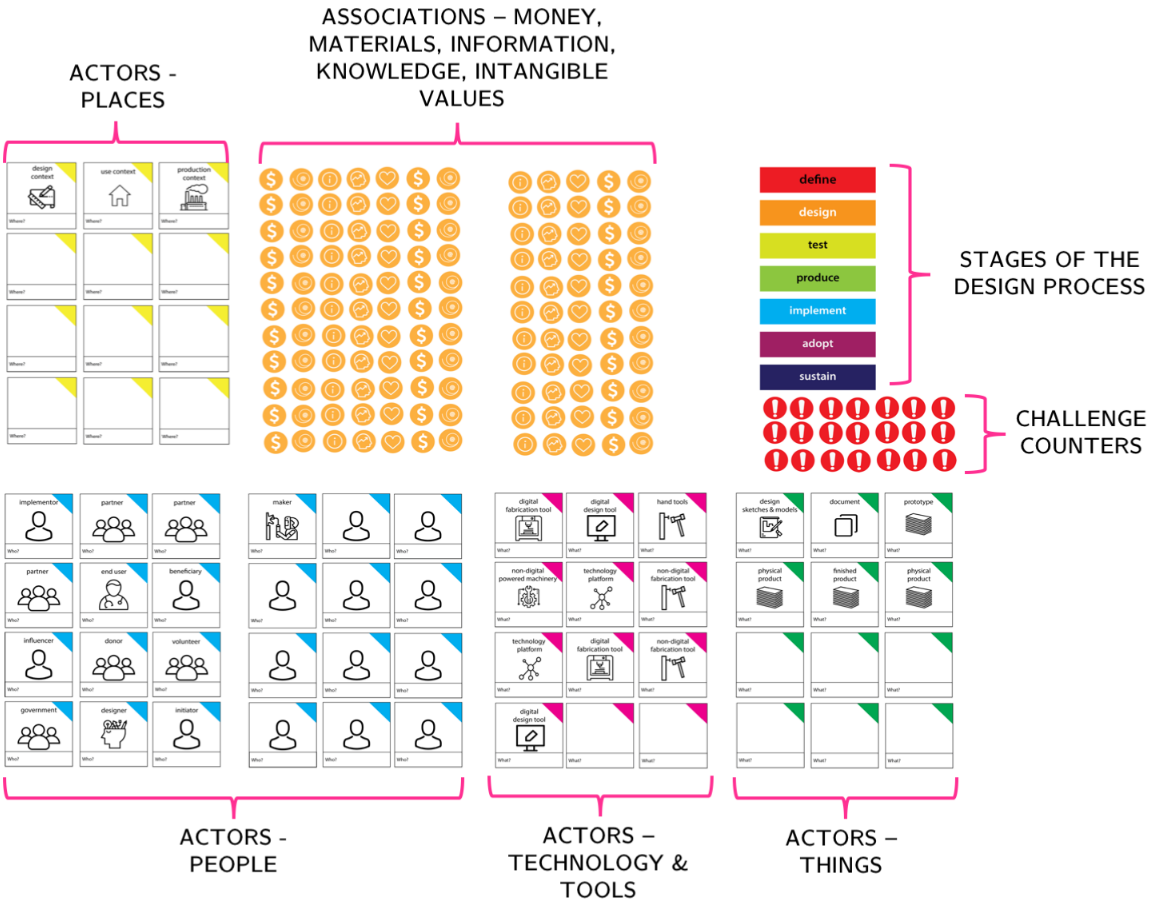


Figure 6.4 – Overview of the contents of the Designet toolkit

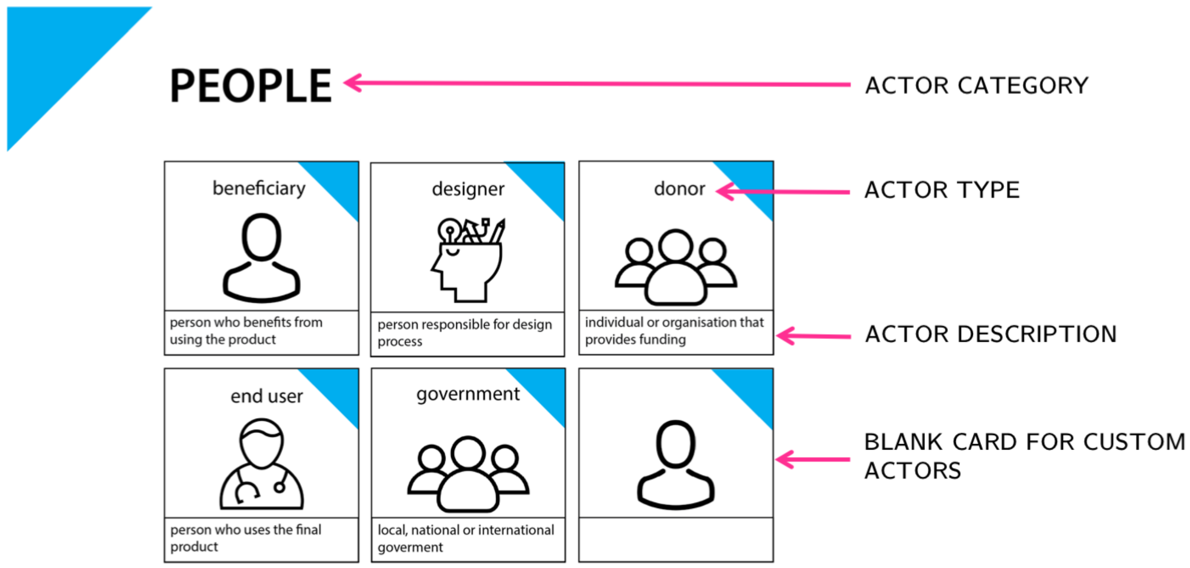


Figure 6.5 – Visual glossary for the actor cards

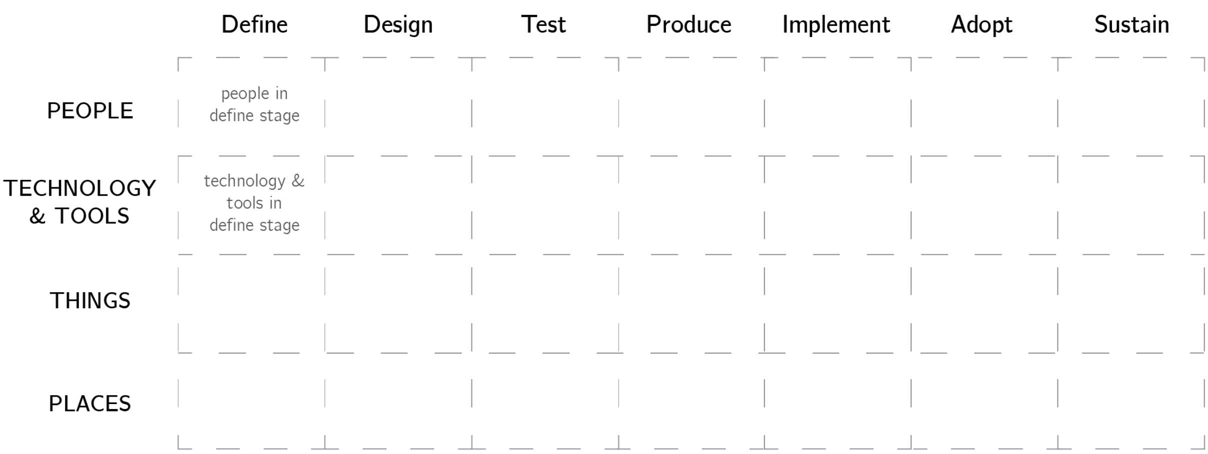


Figure 6.6 – Template for mapping the networks

6.5.3 Defining the workshop protocol

After several refinements a final workshop protocol was created for mapping the networks of DF4D projects (see Appendix Table 4). The mapping process is guided in stages by the facilitator to support the participants. First, participants are asked to identify the actors involved in the initial stage of the design process by selecting the cards for people, technology and tools cards, things and places. Second, they can add descriptions to these cards and place them on the map. Third, the participants are invited to draw the connections between these actors, by using lines and arrows to indicate the direction of these interactions. These steps are repeated for the following project stages.

The result is the creation of individual maps for each stage of the project. Once the whole mapping process is complete, participants are asked to reflect on how the current DF4D project advances or limits social sustainability. They are invited to place challenge counters on the parts of the network that they perceive to be particularly problematic. In doing so, they are asked to reflect on their current practices and to imagine what the DF4D project might look like in the future. Specifically, they are asked to consider practices that advance or limit social sustainability. Finally, feedback is gathered from participants about the workshop, to understand how the workshop impacted their understanding of the practices that potentially advance or limit social sustainability. In total, the workshop is scheduled to take between 1.5-2 hours, depending on how many stages of the project are mapped out.

6.6 Collecting data about the case studies using the Designet toolkit

The Designet toolkit was used to collect data about the three DF4D projects presented in the previous chapter. Workshops were conducted with the organisations involved in the case studies between April – September 2018. The first case study (CS1) was a 3D printed otoscope, designed by Field Ready. The second case study (CS2) was a digitally fabricated leg prosthesis, designed by BETiC at IIT-B. The third case study (CS3) was a digitally fabricated suction pump machine, designed by Makerspace/FabLab Nairobi. Table 6.5 provides details about each of the workshops. Appendix Figure 1 shows some photographs of the workshops.

Prior to the field work, an ethics and risk assessment form was approved by the Department of Engineering, University of Cambridge. All the participants were provided with a participant information sheet and a written consent form to complete in advance of the workshop. Verbal consent to record the workshop (with audio and photography) was confirmed again at the start of the workshop. In this study, truly informed consent was obtained by making it clear to participants how the data would be used and the expected outcomes of the research. Network analysis requires additional efforts to protect harm to innocents because it can include non-respondents (Borgatti & Molina, 2003, 2005). Care was taken to pseudonymise the data unless respondents requested their own identification. 'Respondent give-back' was also set out to ensure an equitable exchange between the researcher and participants (ibid). In this case, the key findings of the study were shared with each of the case studies.

Table 6.5 – Overview of the workshops

Case Study	DF4D project	Organisations	Participants	Date	Duration
1	Otoscope	Field Ready	Innovation lead (CS1-1), design lead (CS1-2), senior designer (CS1-3), junior designer (CS1-4), junior designer B (CS1-5)	April 2018	2.5 hours
2	Socket for Prosthetic	BETiC at IIT-B	Clinician (CS2-1), designer (CS2-2), junior design (CS2-3), junior designer (CS2-4)	May 2018	2.5 hours
3	Suction pump machine	Makerspace/FabLab Nairobi	Design lead (CS3-1), designer (CS3-2)	September 2018	1.5 hours

The first two workshops took 2.5 hours, which was longer than the workshop protocol had originally planned for. In both workshops, fruitful discussions and explorations of controversies extended the duration of the workshops. In the last workshop, a more conscious effort was made to drive on the mapping process and this lasted 1.5 hours. This workshop only involved two participants which also meant there was less discussion.

All the workshops were audio recorded and transcribed verbatim after. Photographs were taken throughout the workshops to document the maps and the participants' engagement. At the suggestion of the participants at FabLab/MakerSpace Nairobi, a video of the workshop at CS3 was also recorded. In addition, detailed notes were made by the researcher after each workshop. These included reflections on the participants' engagement with the toolkit and mapping process, as well as key observations about the networks of the DF4D projects. At the end of the second and third workshop, previous notes were referred to in order to compare the cases.

Although the workshops aimed to convene as many different types of stakeholders (including designers, end users and beneficiaries), it did not prove possible for anyone other than the 'expert' design team[14] to participate in the workshops. Other actors did not participate because of time constraints, logistics challenges or lack of responsiveness. Although this was

[14] 'Expert' is written in inverted commas to acknowledge the reality that other actors, including end users and beneficiaries can provide significant expertise in the design process. More broadly there is a shift in design, away from 'expert design' to 'diffuse design', in acknowledgement of the capabilities of people who are not formally trained (Manzini, 2015b).

disappointing, it was not completely unexpected as the challenges of enabling participation in participatory activities are well-known (Andersen et al., 2015). Regardless the workshops provided valuable insights on the networks of DF4D projects, from the perspectives of the 'expert' design team.

6.7 Reflections on the Designet toolkit and workshops

The suitability of the Designet toolkit for mapping the networks of DF4D projects was reflected upon after the workshops. Particular attention was paid to both the explicit feedback received at the end of the workshops and the behaviours and interactions that were observed during the workshops.

First, it was found that the workshop did indeed help to build a shared reality of the DF4D projects. The workshops were useful for key actors in the design process (e.g. lead designers), as well as actors who had less visibility in the network (e.g. junior designers).

- *CS2.2: It was good to see it all mapped out, now it started to all make sense. Even us who work on it a lot, don't know the whole picture.*

This suggests that these workshops would also be highly valuable for other actors outside of the design team who typically have less visibility of the networks (e.g. end users, donors). Although the workshops aimed to include these groups, only stakeholders from the main design organisations were able to attend. Future workshops should try to mitigate against this by identifying effective ways to encourage wider attendance.

Overall, storytelling was a powerful tool to help elicit the maps. Participants naturally described the design process, whilst selecting actor cards and mapping the interactions. Sometimes the participants struggled to map discrete stages and would need to be prompted that they should only focus on the stage currently being mapped. In the design and test stages, this linear separation was impossible as the participants believed that these stages were iterative. This supports cyclical models of the design process and underlines the inherent difficulty of trying to mitigate complexity whilst accurately mapping the networks. The decision to map the DF4D project in stages was driven by a desire to simplify mapping the networks, however it had the unintended effect of confusing participants who found it difficult to distinguish between project stages. Hence it was found that balancing the need for simplicity with the need for detailed representations was challenging. Future workshops might consider mapping the design process without focusing on design stages or at least allowing participants to identify their own stages. These initial workshops suggest that storytelling might be sufficient to help structure the mapping process without confusing participants.

- *CS3.1: Mapping this design process was a real test! It's a complex product and we are constantly iterating.*

Second, the workshops helped participants to explore the actors' identities and interactions in detail. Participants quickly understood the concept of actors and interactions and it was interesting to note that they did not struggle at all with the concept of mapping human and non-human actors. The toolkit allowed for an explicit examination of the strength and direction of relationships, which must normally be inferred in other data collection methods such as interviews. The actor cards were also useful for prompting discussions about the roles of different actors. For example, in CS2 participants debated whether one organisation was a partner or not.

- *CS2.3: How were Company X partners?*
- *CS2.1: We had their machines and our license was ending. They offered to do the work at their facilities.*
  CS2.3: But they don't seem like partners… they are not related to the project in any way. You asked something of them and got something back.
  CS2.1: But I think they were more partners.
  CS2.2: They have spent some resources so we would like to appreciate that effort.

On one hand, the actor ontology helped to speed up the mapping process and encourage people to get started; selecting the cards often revealed hierarchies that were not otherwise discussed by the design team. On the other hand, participants often deliberated for a long time to select the 'right' card. Whilst the prescribed actor cards did not inhibit the participants' ability to think beyond these, it was observed that the large number of actor cards (in particular for the people actor category), delayed the identification of actors in the network. One recommendation for a future version of the toolkit is to reduce the number of actor types and to encourage participants to fill in more blank cards for 'out of the box' actors. On the whole, the blank cards were well used and this supports the idea that people should be allowed to define their own ontology. However, there was sometimes confusion between organisations and people within the people category. Also groups of people were sometimes identified using one actor card. For example, in CS3 the nurses at KNH were represented by one end user card. In this case, the group were considered homogeneous enough that one card was sufficient. However, a future toolkit should also consider whether it might be valuable to include organisations as a separate actor category.

Third, the workshops provided an opportunity to reflect on current practices and explore controversies. Specifically the workshops encouraged participants to question other actor's decisions and they were able to reflect on things that they would do differently in hindsight. They were also alerted to how specific interactions might have been overlooked in the design process.

- *CS1.2: Did you look into any medical device testing standards?*
  CS1.3: No.
  CS1.2: I think we should do that.
- *CS2.1: It helped us see what we might skip in our thinking. For example the collaborations with IIT-G and IIT-M. We didn't included Mobility India in that stage, we only got that idea later.*

The workshop enabled the participants to recognise current and future challenges. The challenge counters provided an easy way to identify problematic parts of the networks and helped to structure the discussion. Naturally, participants would rank the challenges in the discussion, according to their perceived difficulty and impact. Future challenges tended to be more speculative and led to debates on different future scenarios. It was found that participants demonstrated broad and holistic thinking when discussing the challenges and started to open up to the possibility of failure. This is particularly significant in the aid sector, which has often been criticised for ignoring failure. Thus, the workshop gave participants the ability to be critical of their own practices in a way that does not normally occur during DF4D projects.

- *CS2.1: It might fail because someone comes up with something better, because we are too tied to our approach. Or someone might donate a lot of money and provide other prosthetics free of cost, the government might decide to promote another prosthetic.*
- *CS1.1: We haven't built the right relationships with iNGOs.*

CS1.3: Yeah, we need to engage more. They have their own procurement process, so we need to understand the supplier relationship and focus more on the final product.

Finally, the workshops helped to identify future visions for the DF4D projects and to identify actions that could be taken to advance social sustainability. Notably the workshops led to discussions and conflicting ideas about which actors should be involved in the future. It was often surprising that there was little agreement about future scenarios, and this itself highlights the value of convening participants to negotiate future steps. Naturally this vision-setting helped participants to reflect on the types of actors and interactions that would be necessary to advance social sustainability.

- *Facilitator: Who else needs to be involved [in the future]?*
  CS2.1: Government, if possible. Implementors, other NGOs.
  CS2.2: I'm not sure about government, we're trying to make the project totally sustainable without government intervention.
- *CS1.3: I think this session is personally going to help me a lot, to think more strategically about the upcoming design stages.*
- *CS3.2: Thinking about the next steps is very helpful for us to plan how we can make sure that the suction pump machine will be sustainable.*

In general, the workshops with more participants led to a wider diversity of perspectives and provided good stimulus to explore potentially conflicting opinions. This resulted in fruitful discussion which helped to guide collective vision-setting and decision making. In the future, it is recommended that the workshop is organised with 4-8 participants and that they should reflect a diversity of different actor types.

6.8 Analysing the networks of the case studies

The following sections will now focus on analysing the networks of the DF4D projects. The maps produced in the workshops provided visually messy but data-rich representations of the networks in three DF4D projects. Appendix Figures 2, 3 and 4 show the maps that were drawn in the workshops for each case study. Each of the maps is actually a representation of two networks: one for the define stage and one for the design and test stage. In analysis, it was therefore necessary to combine these separate representations into a single network for each DF4D project. In order to achieve this and at the same time, produce high quality visualisations, it was decided to use a network visualisation software to assist with data analysis.

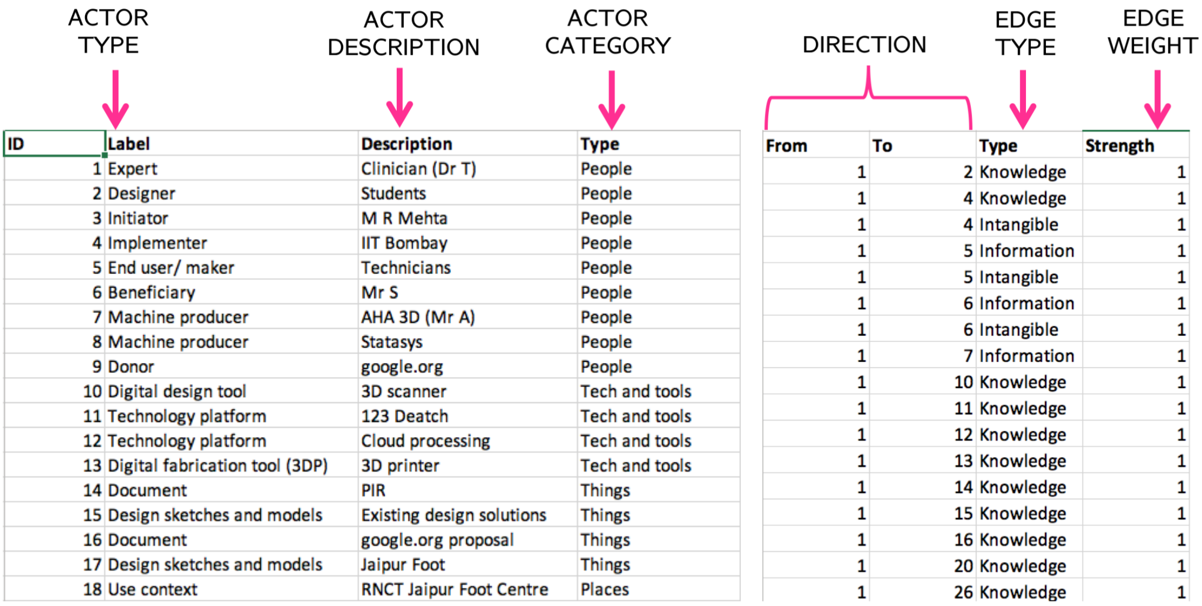
6.8.1 Using Kumu to help analyse the data

After reviewing several software tools, Kumu, a web-based platform was chosen. It was selected because of its ability to represent multiple edges between nodes, as well as its ability to handle directed and weighted edges. Other popular software like Gephi, yEd and UNINET 6 do not allow for the representation of multiple edges between nodes. For example, it is possible to show an association between two actors but it is not possible to show that money *and* materials are being exchanged between two particular actors. In Kumu, all public maps are free to create and they can be easily accessed online via a hyperlink. In addition, Kumu is interactive and it allows the viewer to focus on specific nodes and edges. Furthermore, it is possible to filter the map view by different types of edges and nodes to investigate particular aspects of the network. Each of these views can be shared with a unique hyperlink. This is a valuable way of sharing data and is aligned with Röhle's (2012) calls for digital researchers to provide 'companion websites' to support academic publications. It also opens up the possibility for stakeholders to own the networks after the study, responding to the need for 'give-back' in research on networks (Borgatti & Molina, 2005).

Kumu offers several different templates for visualising networks. In this study, the stakeholder template was selected because of its ability to represent directed networks. To manage large networks, data should be prepared in a .csv file and imported to Kumu. This requires the creation of a node list and edge list, which must be structured in a specific format (see Figure 6.7). In Kumu nodes or actors are referred to as elements, and associations or edges are referred to as connections. The node list includes information about the actors in the network, and should include the first two columns: ID (unique identifier) and Label (actor type e.g. designer, end user). Optional columns include Description (actor description e.g. Mr S, Organisation A) and Type (actor category e.g. people, technology and tools). The Edge list must include the columns 'From' and 'To' to indicate the direction of the Edge; 'Type' indicates the Edge type e.g. knowledge, information; and, 'Strength' indicates the edge weight. Strong connections represented by a solid line are given a strength of 1, weak connections represented by a dashed line are given a strength of 0.5.

In order to prepare the data for Kumu, photographs of the network maps were converted into node and edge lists. These representations were reviewed by the researcher to ensure that the node and edge lists were as accurate and detailed as possible. The lists were first sense checked to identify any obvious missing connections. For example in CS1, a connection had been omitted between the maker and the 3D printer. A knowledge flow from the maker to the 3D printer was therefore included. The researcher also paid attention to the transcripts of the workshop audio recordings to identify any actors/associations, that had been discussed but were not physically mapped during the workshop. For example, in CS1 an intangible relationship between the designer and the material supplier was discussed in the workshop, however this was not represented in the map. Apart from this, the network maps were found to be consistent with the researcher's understanding of the cases, built from the interviews, observations and reports reviewed in the analytical study in Chapter 5.

These lists were then imported to Kumu to automatically generate the networks. Kumu also allows the user to edit networks. For example, different colours can be assigned to different edge types and node types. The size of the nodes can also be adjusted to reflect the degree of the node in the network (i.e. the number of connections a node has). Figure 6.8 shows the editor view on Kumu to illustrate how the network was manipulated using the software. Another benefit of Kumu is the ability to produce network analysis metrics, such as degree, in-degree and out-degree. Such metrics can reveal important structural patterns in the network and also help with the comparison of different networks (Barabási, 2016; Coviello, 2005). These metrics will be defined later in the chapter.



ID	Label	Description	Type
1	Expert	Clinician (Dr T)	People
2	Designer	Students	People
3	Initiator	M R Mehta	People
4	Implementer	IIT Bombay	People
5	End user/ maker	Technicians	People
6	Beneficiary	Mr S	People
7	Machine producer	AHA 3D (Mr A)	People
8	Machine producer	Statasys	People
9	Donor	google.org	People
10	Digital design tool	3D scanner	Tech and tools
11	Technology platform	123 Deatch	Tech and tools
12	Technology platform	Cloud processing	Tech and tools
13	Digital fabrication tool (3DP)	3D printer	Tech and tools
14	Document	PIR	Things
15	Design sketches and models	Existing design solutions	Things
16	Document	google.org proposal	Things
17	Design sketches and models	Jaipur Foot	Things
18	Use context	RNCT Jaipur Foot Centre	Places

From	To	Type	Strength
1	2	Knowledge	1
1	4	Knowledge	1
1	4	Intangible	1
1	5	Information	1
1	5	Intangible	1
1	6	Information	1
1	6	Intangible	1
1	7	Information	1
1	10	Knowledge	1
1	11	Knowledge	1
1	12	Knowledge	1
1	13	Knowledge	1
1	14	Knowledge	1
1	15	Knowledge	1
1	16	Knowledge	1
1	20	Knowledge	1
1	26	Knowledge	1

Figure 6.7 – Node list and edge list prepared for Kumu

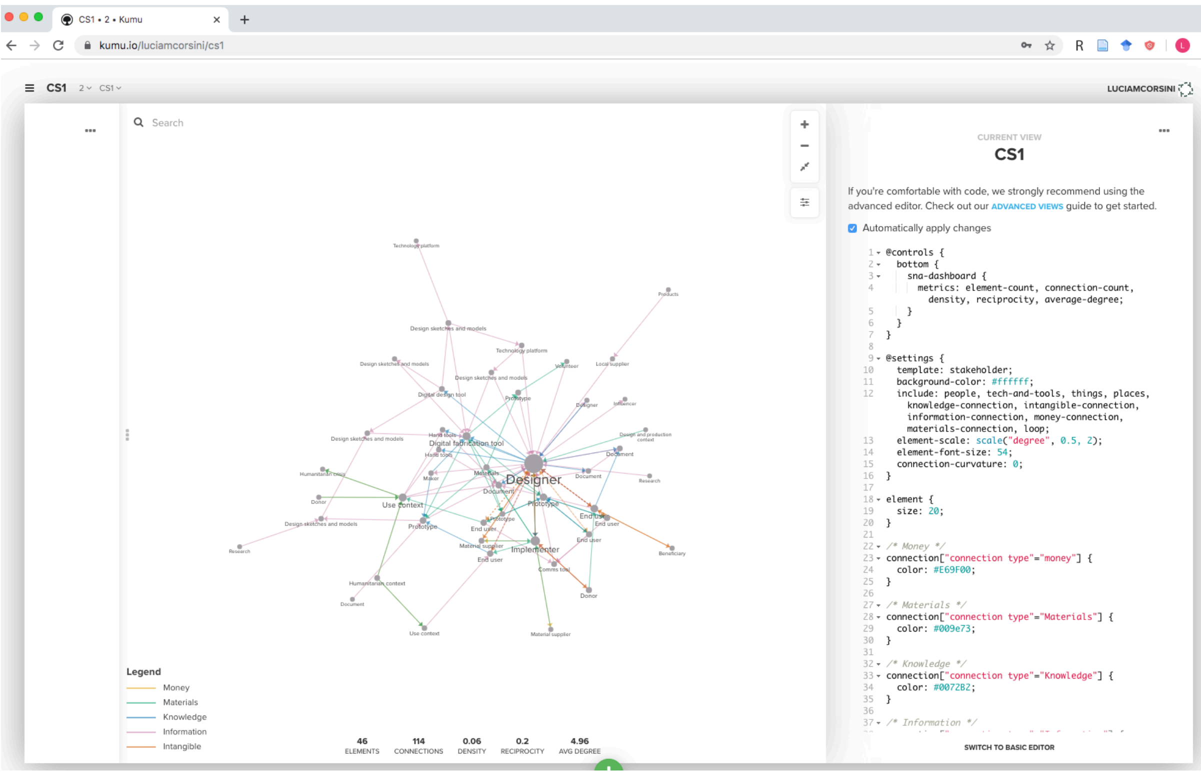


Figure 6.8 – Using Kumu to manipulate the network

6.8.2 A mixed methods approach to analysing the networks

It was decided to use a mixed methods approach to analyse the networks. Although Latour was initially keen to distance ANT from quant-heavy network perspectives[15], the lack of prescriptive approaches in ANT has opened the door to quantitative analysis being used to complement qualitative descriptions (Boullier, 2018). In recent years academics have advocated for the use of quali-quantitative methods in ANT and in a paper co-authored with Latour, Venturini et al. (2017) state that the use of digital tools in network analysis "*demands to rethink our methods and, in particular, the classic opposition between qualitative and quantitative approaches*." It is put forward that quantitative analysis can highlight important structural patterns, whilst qualitative analysis can help to explain local interactions and their meanings (Venturini, 2010; Venturini et al., 2017). It is also suggested that digital tools naturally reveal a 'quali-quantitative continuum' by allowing for analysis across a variety of scales (ibid). In other work, Aranda-Jan (2018) uses ANT to investigate the design context, arguing that the combination of qualitative and quantitative methods provides different perspectives on the network and further validates findings. In summary, qualitative and quantitative network approaches have complementary strengths and weakness and thus offer valuable contributions when used together (Crossley, 2010). Digital tools make this new reality possible and are therefore important in analysing networks.

6.8.3 Network analysis metrics

Several metrics have been developed in network science that can be used at the node-level or overall network-level. To analyse networks, it is important to develop an understanding of the mathematical formulations than underpin the key network metrics (Barabási, 2016). The following section will explain and define the metrics that inform this study.

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[15] "By the way, I am sorry to say that what I mean by actor-network bears no relation with the same term in Barabassi's LINKED, by which he means the league or the union of real actors from nearby Hollywood! No, alas, mine is a purely conceptual term that means that whenever you wish to define an entity (an agent, an actant, an actor) you have to deploy its attributes, that is, its network ." (Latour 2011, p. 5)

Size

Generally the size of a network is represented by the number of nodes (N). The number of edges (E) represents the total number of edges that connect the nodes.

Density

The density of a network represents the ratio of actual connections (E) to potential connections. In a directed network this is calculated using the following equation. Sparse (low density) networks are structured more like chains, and can be vulnerable to points of failure (Faust, 2006).

$$d = \frac{E}{N\ (N-1)}$$

Degree

An important property of a node is its degree (k_i^{tot}), which is the number of edges it has to other nodes (Golbeck, 2015). In general, elements with high degrees are local connectors or hubs. They have high influence on their immediate neighbours, however it should not be assumed that they are well connected to the wider network (ibid). In directed networks, the total degree of a node is the sum of in-degrees (k_i^{in}) and out-degrees (k_i^{out}).

$$k_i^{tot} = k_i^{in} + k_i^{out}$$

In-degree

The in-degree $\left(k_i^{in}\right)$ of the node i is the total number of connections directed towards node i. Broadly speaking, nodes with high in-degree are the leaders and have expertise in the network (D. Hansen et al., 2011).

Out-degree

The out-degree $\left(k_i^{out}\right)$ of the node i, is the total number of connection directed out of the node i. Nodes with high out-degrees are able to reach a high number of other nodes and are important for transferring resources in the network (ibid).

Average degree

The average degree is the average number of edges for any node in the network. For directed networks this is calculated using the following equation.

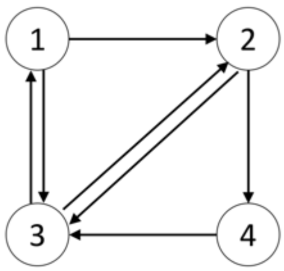
$$\langle K \rangle = \frac{E}{N}$$

$$\langle K \rangle = \langle K_{in} \rangle + \langle K_{out} \rangle \; where \; \langle K_{in} \rangle \,! = \langle K_{out} \rangle$$

Reciprocity

The reciprocity tells you the ratio of the number of links which are reciprocated (i.e. there is an edge in both directions) to the total number of links in the network, in which two nodes are linked if there is *at least* one edge between them. In other words, reciprocity tells you the likelihood that two nodes will have an equal number of edges in either direction between them. Reciprocity is therefore a useful indicator of mutuality and exchange in the network. In a weighted network, the reciprocity (r) is the ratio of the number of weighted reciprocal links ($W \leftrightarrow$) over the number of weighted links (W) (Squartini et al., 2013). Figure 6.9 illustrates the reciprocity of a simple network.

$$r = \frac{W \leftrightarrow}{W}$$



$$r = \frac{2}{5} = 0.4$$

Figure 6.9 – Reciprocity of a simple network

6.9 Overview of the networks

This section is dedicated to describing the networks of the three DF4D projects included in the main study. Figures 6.10, 6.11 and 6.12 show the networks for the respective case studies. The size of each node represents its degree. The type of association between actors is represented by the colour of its connections. These figures provide a limited representation of the networks, however they can be viewed more fully in dynamic form online via the following links: https://kumu.io/luciamcorsini/cs1 (CS1); https://kumu.io/luciamcorsini/cs2 (CS2); https://kumu.io/luciamcorsini/cs3 (CS3). It is possible to navigate through different views of each network to focus on particular interactions and actors in the network. The reader is strongly encouraged to view and explore these networks online.

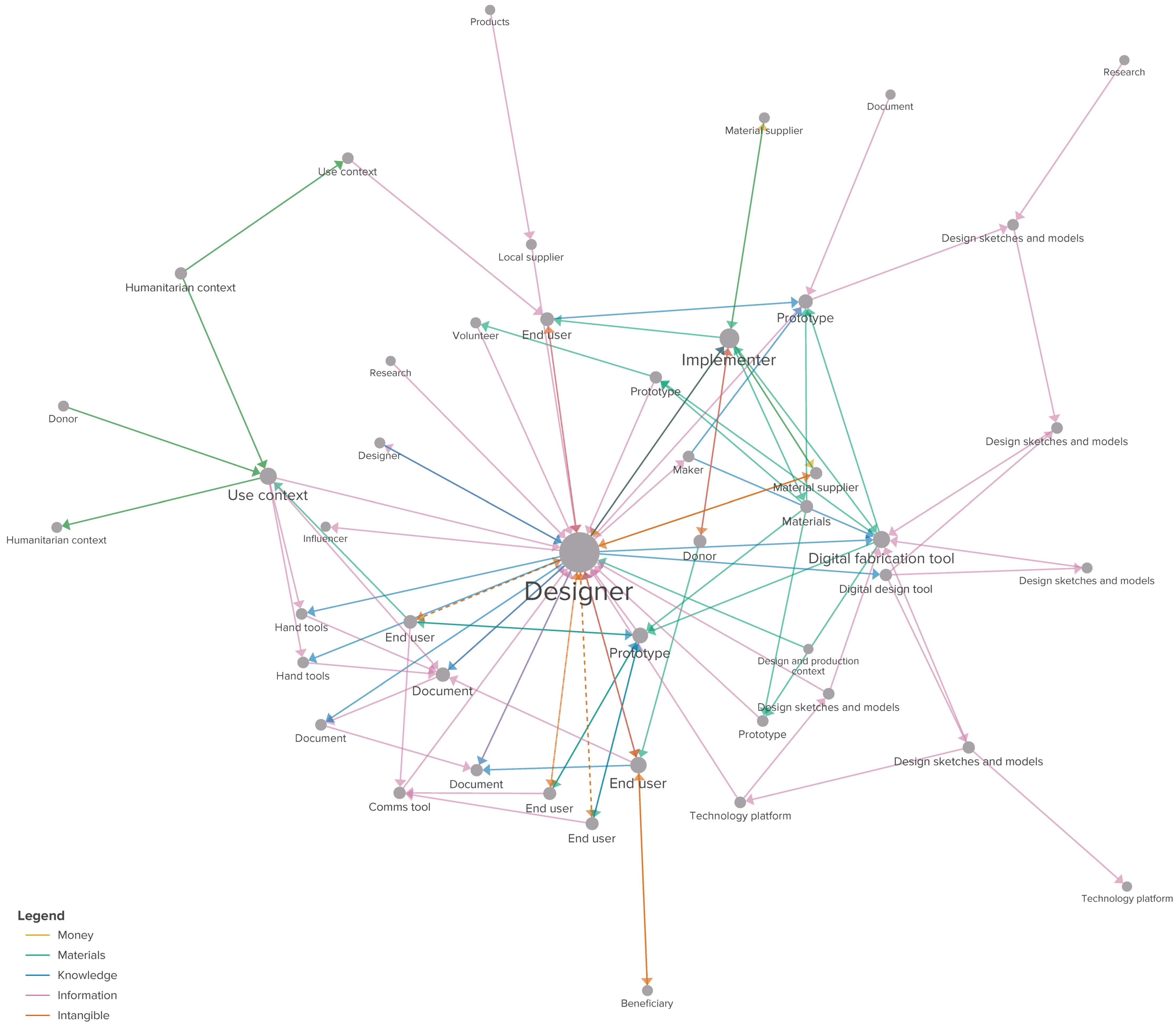


Figure 6.10 – Network of Case Study 1

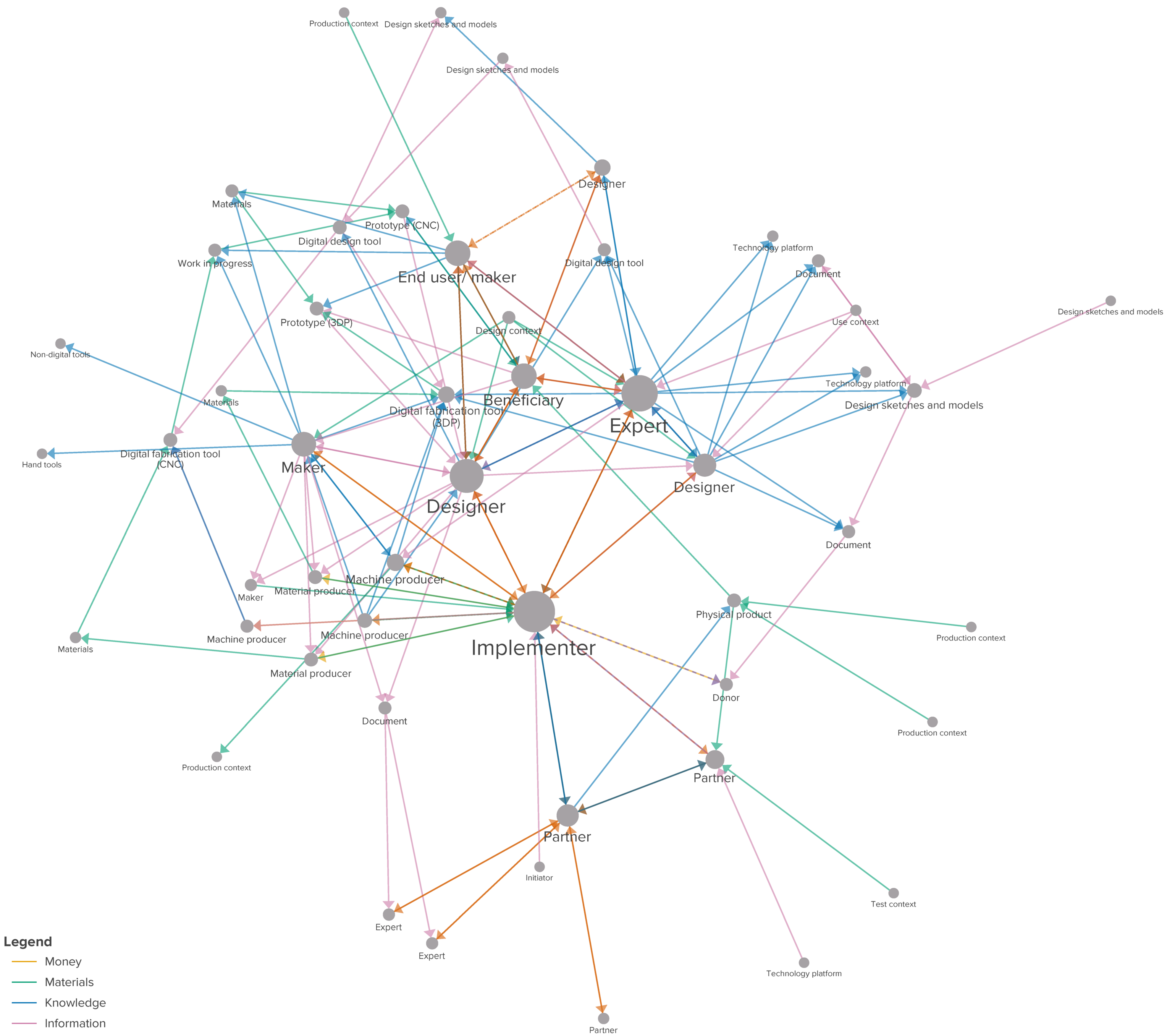


Figure 6.11 – Network of Case Study 2

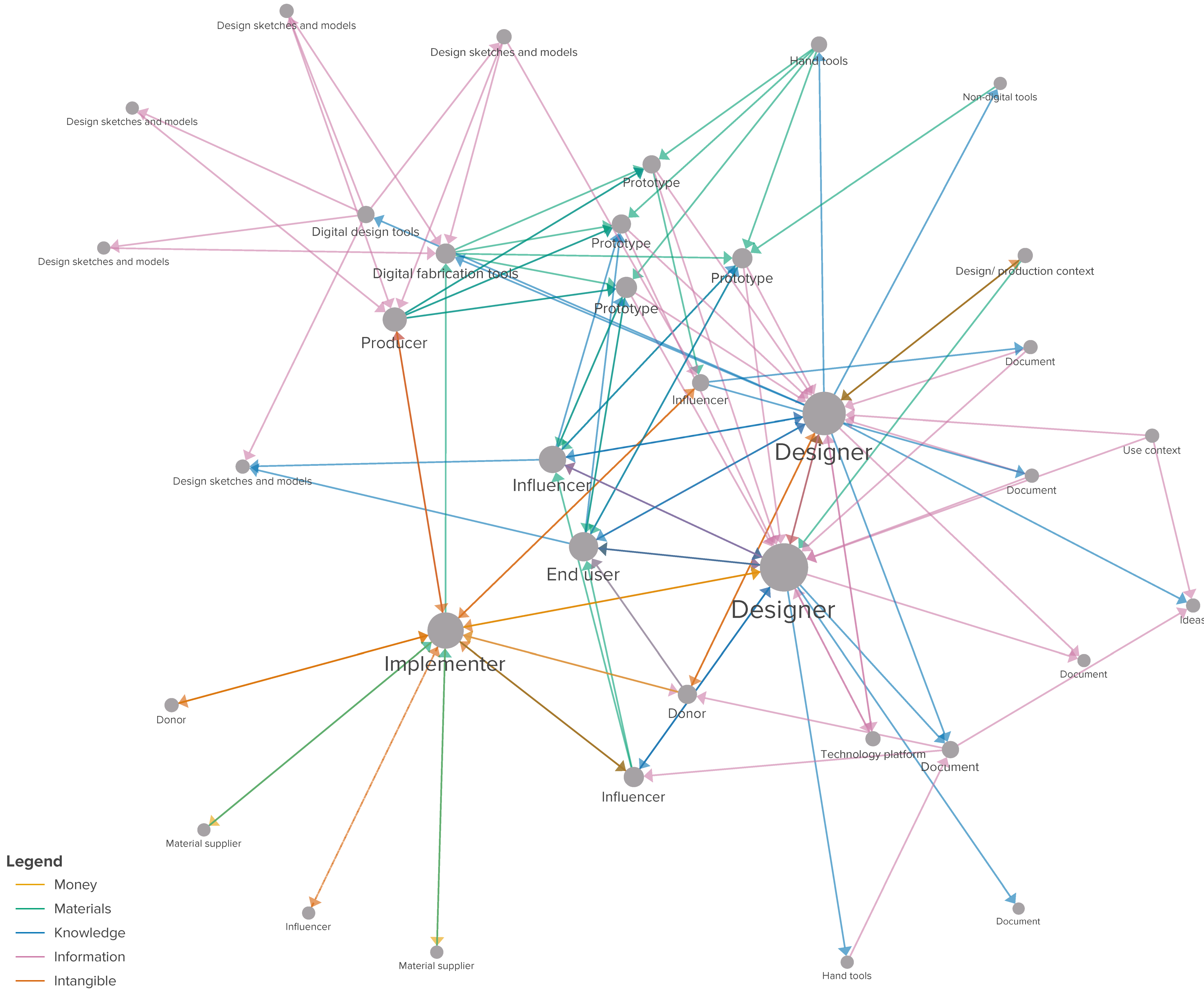


Figure 6.12 – Network of Case Study 3

Table 6.6 provides an overview of some key metrics for the networks of CS1, CS2 and CS3. In this study, the networks are relatively small in size and only a few cases are presented. Consequently, these metrics are not intended to be statistically rigorous, but rather provide some interesting insights that can be complemented by qualitative analysis.

First, it noted that the size of the networks is in the same order of magnitude for each case study. Looking at the size of the networks by node type, the *people* category is largest in CS1 and CS2, whereas the *things* category is slightly higher in CS3. In all cases, the majority of nodes are non-human, which provides further evidence of the importance of including non-human actors in network analysis.

Taking into account the relative number of nodes and edges, it can be seen that CS3 has a slightly higher density than CS2 and CS1. This implies that a greater proportion of potential edges are realised in this network. Overall, this corresponds with the metric for average degree, which is greatest for CS3 (7.67), followed by CS2 (6.73) and then CS1 (4.89). The total reciprocity is greatest for CS2 (0.29), then CS3 (0.25) and CS1 (0.20). This reveals that interactions are more likely to be reciprocated in CS2 than in the other cases. Later, this section will investigate reciprocity in more detail by examining the mutual exchange of specific edge types.

Table 6.6 – Overview of some key metrics for the networks of CS1, CS2, and CS3

Case study	Size ($\boldsymbol{N}$)	Number of edges ($\boldsymbol{E}$)	Average degree $\langle \boldsymbol{K} \rangle$	Density $\boldsymbol{d}$	Reciprocity $\boldsymbol{r}$	Number by node type			
						People	Technology and tools	Things	Places
1	46	114	4.89	0.06	0.20	17	7	17	5
2	51	170	6.73	0.07	0.29	21	9	14	7
3	36	137	7.67	0.11	0.26	13	6	15	2

6.9.1 Which actors are present in the network?

To begin with it is important to recognise the diversity of actors present in the networks. Among the non-human categories, the three networks feature similar elements. In terms of *technologies and tools*, the networks include a combination of digital and non-digital fabrication tools, as well as digital design tools and infrastructure. With respects to *things*, all the networks refer to documents, prototypes and design sketches. They also identify specific *places* for use, design and production. The main differences between the networks is in the *people* category.

Whereas the networks for CS2 and CS3 include only a small number of end users, several end users are identified in the network for CS1. On one hand, a network with several nodes is more resilient to the removal of any nodes. In this example, the designer is less reliant on any single end user for information and this also reduces the burden of engagement for the end user. On the other hand, it creates an additional burden for the designer to establish and maintain relationships with multiple end users. In CS1, the end users seem to play a more superficial role and it is observed that they are located on the peripheries of the network. It is also notable that the beneficiaries (the patients who receive care) are absent in networks of CS1 and CS3. In contrast, the beneficiary is a central node in the network of CS2.

Overall, CS2 includes the most diverse type of actors, involving a large number of partners from the wider ecosystem. For example, BETiC at IIT-B (the implementer) collaborate with actors across the supply chain. Whereas all the case studies engage with end users/beneficiaries to some extent, the network for CS2 also includes several actors in the upstream supply chain, such as machine producers and material suppliers. In addition, several institutional partnerships exist, connecting research between various institutions in India.

It is also worth highlighting that the actor who initiates the project is different in each of the case studies. Although this card was only selected by the participants in CS2, each of the projects were triggered by different actors. In CS1 the initiator was the implementer, Field Ready who decided to visit a rural health-post, based on their experience that 3D printing could produce valuable items for clinics. In CS2, the initiator was Dr Rajiv Mehta, the owner of a charity that manufactures prostheses. He approached BETiC in search for a way of scaling-up his manufacturing process. In CS3, the donor Concern Worldwide initiated the project after recognising the potential for FabLab Nairobi to help manufacture locally-appropriate medical devices. Acknowledging who initiates the project is important for understanding their motivations and potential benefits.

6.9.2 How do actors participate in and influence the network?

To explore how actors participate in the networks, close attention was paid to the degree, in-degree, out-degree of individual nodes.

First, for each network the degree of every node was extracted from Kumu. To determine the most important hubs in each network, attention was paid to the nodes with the highest degree. As the relative influence of each node was of interest, it was decided to compare how these values ranked instead of focussing on their raw values. Table 6.7 shows the top five nodes ranked by degree for each network. The raw values are shown in brackets to enrich intra-case study comparison, but should not be used for inter-case comparison. Tables 6.8 and 6.9 indicate the in-degree and out-degree for the top ranked nodes respectively.

Table 6.7 – Top five nodes ranked by degree

	Case study 1	**Case study 2**	**Case study 3**
#1	Designer 1 (45)	Implementer (38)	Designer 1 (37)
#2	Implementer (15)	Expert (32)	Designer 2 (35)
#3	Digital fabrication tool (11)	Designer 1 (29)	Implementer (22)
#4	Use context (11)	Beneficiary (21)	End user (18)
#5	End user (10)	End user/ maker (20)	Influencer (16)

Unsurprisingly, designers are identified as important hubs in the networks. Typically they are responsible for gathering information from other stakeholders to formulate design briefs. During problem definition, their knowledge informs the analysis of existing products, the development of designs and the creation of prototypes. Their knowledge is also used to reflect on the prototypes and to interpret stakeholder feedback. Across the networks, the designers establish important trust-based relationships with other stakeholders.

The implementers (i.e. Field Ready, BETC at IIT-B and Makerspace/FabLab Nairobi) are also influential hubs in the network. Mostly they control the flow of money in the networks and are also key for enabling relationships and partnerships. Often their institutional reputations provide the social capital needed to establish partnerships with other organisations.

During the workshop with CS1, the lead designer's centrality in the network was recognised by the participants as a potential point of failure. Participants reflected on the fact that limited information or knowledge about the DF4D project had been shared with the implementing organisation or other designers involved in the project. In particular they noted an absence of formal documentation. For example, the designer had gathered valuable feedback from the end users for iterating and developing the otoscope, however their feedback had not been documented in any way. Furthermore the contact details of the end users were not documented.

It was decided by the participants during the workshop that creating these documents would help to mitigate against potential risks, for example if the designer left the project.

In contrast, in CS2 the designer has a lower degree than the implementer (BETiC) and the expert (the physiotherapist). In part, this is a result of conscious decision making in the project to reduce dependency on any single person. Collectively, BETiC expected that individuals might leave during the project and so positioned themselves as the key hub to prepare for any changes in personnel. Another explanation for the expert's relatively highly influence in the project is the fact that they were invited to be part of the design team. The physiotherapist worked full-time at BETiC alongside the designers to develop the prosthesis. This provides clear evidence that positioning experts with the design team maximises their ability to spread information and knowledge.

Across all the networks, end users (and beneficiaries) are among some of the most connected nodes. However it was noted that in CS1, the end user is less connected than the digital fabrication tool and the use-context itself. This implies that the use-context (i.e. the health-post) had greater ability to influence the DF4D project than the end user (i.e. the clinician at the health-post). This means that the designer's assessment of the problem was more informed by their own observations than the information provided by the end users. Similarly, the digital fabrication tool (the 3D printer) was more influential than this particular end user. In part, this is due to the fact that several prototypes were produced by the 3D printer and that this end user was just one of several end users involved in the project. Nonetheless, it suggests that CS1 follows a more technology-centred than user-centred approach.

Looking at the in-degree metric for the nodes reveals more interesting insights in this respect. For CS2, the beneficiary (the patient who receives the digitally fabricated prosthesis) and the end user/maker (the technician who manufactures the traditional prosthesis) are among the human-actors with the highest in-degrees in the network. This means that a significant amount of connections are being directed to them (i.e. they are receiving information, knowledge, materials etc.). Similarly in CS3, end users (nurses who use the suction pump machine) and influencers (bio-medical engineers who repair the suction pump machine) have some of the highest in-degree values in the network. In CS1 it is notable that the end user (the clinician at the health-post) has a lower in-degree than many non-human actors including several prototypes, documents, the use-context and digital fabrication tool. In contrast, the out-degree for this end user is higher than these same elements. This reveals an asymmetry in resources that are being taken and given to the end user. In this case, it appears that information is being extracted from the end user, however there is only a little reciprocity in the way of shared information, knowledge or tangible products being directed to the end user. This is a concern, as it indicates an imbalance in the position of end users in the network. Given that many humanitarian and development projects have been criticised for tokenistic user participation (Prokopy, 2004; Swapan, 2016), it is necessary to scrutinise these relationships further. The following sections will focus on the types of interactions and their reciprocity in the networks.

Table 6.8 – Nodes ranked by in-degree

Rank	CS1	CS2	CS3
#1	Designer (26)	Implementer (19)	Designer (21)
#2	Implementer (7)	Expert (14)	Designer (18)
#3	Digital fabrication tool (7)	Designer 1 (14)	Implementer (11)
#4	Prototype (5)	Beneficiary (10)	End user (9)
#5	Prototype (5)	Partner (7)	Influencer (7)
#6	Document (5)	End user/maker (7)	Producer (fabricators) (6)
#7	Use context (5)	Digital fabrication tool (7)	Prototype (6)
#8	End user (4)	Designer (6)	Prototype (6)
#9	Comms tool (3)	Partner (6)	Prototype (6)
#10	Prototype (3)	Maker (6)	Digital fabrication tool (5)

Table 6.9 –Nodes ranked by out-degree

Rank	CS1	CS2	CS3
#1	Designer (19)	Implementer (19)	Designer (16)
#2	Implementer (8)	Expert (18)	Implementer (14)
#3	End user (6)	Designer (15)	Designer (14)
#4	Use context (6)	Maker (14)	End user (9)
#5	Donor (4)	End user/ maker (13)	Influencer (9)
#6	End user (4)	Beneficiary (11)	Producer (fabricators) (7)
#7	Digital design tool (4)	Designer (10)	Digital design tools (5)
#8	Humanitarian context (4)	Partner (8)	Donor (5)
#9	Digital fabrication tool (4)	Machine producer (5)	Influencer (5)
#10	Materials (4)	Partner (5)	Prototype (4)

6.11.3 What type of interactions take place in the networks?

Table 6.10 provides an overview of the interactions that take place in the case studies. Across all the networks, information is the most common type of association or edge. This means that actors are often sharing or exchanging information in the network. This can include information sharing between people. For example, in CS3 the nurses provide information to the designers about the challenges they face whilst working on the maternity ward. They inform designers about the lack of suction pump machines and the unsuitability of current machines for the local context. Information can also be directed from non-human actors to other non-human actors. For example, digital data is directed from the digital design software to the 3D printer. In addition, information can be directed from non-human to human actors. Taking another example from CS3, design briefs are created which provide information on product requirements to the design team. Similarly prototypes give information to the designers on their suitability (in the same way that products can afford actions (Gibson (1979)).

Table 6.10 – Overview of interactions in the networks of CS1, CS2 and CS3

Case study	Size (N)	Number of edges (E)	Number by edge type					Reciprocity r
			Information	Knowledge	Material	Money	Intangible	
1	47	114	47	17	24	8	18	0.20
2	52	170	51	50	26	5	38	0.29
3	36	137	50	33	26	6	22	0.26

In CS2 and CS3, knowledge is the second most common type of interaction. It is notable that for CS2, the number of knowledge edge-types is almost the same as the number of information edge-types. In comparison, the proportion of knowledge edge-types is roughly a third of information-edge types in CS1. The flows of knowledge in the network can be shared between people. For example in CS3, the nurse shares her knowledge on how to operate the traditional suction pump machine and how to care for patients with the design team. Flows of knowledge can also be directed from human to non-human actors. For example, the nurses' experience is used to evaluate the prototypes for the locally-manufactured suction pump machines. In this sense, their knowledge is used to act on the prototypes. Things (e.g. prototypes, documents) therefore play an important role in mediating knowledge and convening information across a complex design process.

Other tangible interactions include money and materials. With respects to money, this interaction begins with the donor who directs money to the designers, material suppliers, material producers and machine producers via the implementers. In CS1, the participants also mapped how the humanitarian context (the earthquake) effectively removed money away from the use context (the health-post), and later indicated that the recovery context (the recovery stage of humanitarian crisis) led to money being donated to the use context (other health-posts). Materials are directed between many actors in the networks, to enable the tangible production of artefacts. These flows of materials are fairly similar across all of the networks, to the effect that the number of material-edges are roughly the same for the three networks.

Finally, intangible values are always bidirectional in the networks. For example, mutual trust between the designers and implementers helps to foster an enabling environment which gives rise to new solutions. Participants also identified how designers show respect and care for end users and in exchange, they are given trust, which helps to build empathy and engagement. Between the implementers and partners, trust helps to establish equitable relationships. The participants also pointed out that the implementer's reputation could give credibility to other partners. For example, in CS2 BETiC worked with AHA!, an Indian start-up manufacturing 3D printers. Through this collaboration, BETiC transferred some of their status and credibility to AHA!, which helped them to grow their business. In some cases, this transfer of status was exchanged for monetary value. For example, Stratasys partnered with BETiC to provide free 3D printing of parts. In return Statasys benefit from publicly supporting an innovative project to help people at the Bottom of the Pyramid. Recognising these exchanges is very important as it highlights the different motivations of actors that may influence the overall social sustainability of DF4D projects.

6.9.3 How is reciprocity shown between actors in the network?

Examining how reciprocity takes place in the network is useful for understanding how mutuality is manifested (Garlaschelli & Loffredo, 2004). Mutuality can be a useful indicator of equitable relationships and is also considered to be necessary for enabling participation among actors (Gallos et al., 2012). Thus, it deserves particular attention when considering how DF4D projects might be designed to promoted social sustainability.

With a view to examine the reciprocity of the networks in more detail, the reciprocity scores of the individual edge types were computed from Kumu (see Table 6.11). For obvious reasons, there is never a mutual exchange of materials or money between two actors. This is because money is always being transferred in exchange for another resource, and materials are being directed along the supply chain from the suppliers upstream to the consumers downstream. As discussed earlier intangible values are always mutually reciprocated because they are manifested through the relationships between actors.

Table 6.11 – Reciprocity of the networks by edge type for CS1, CS2, and CS3

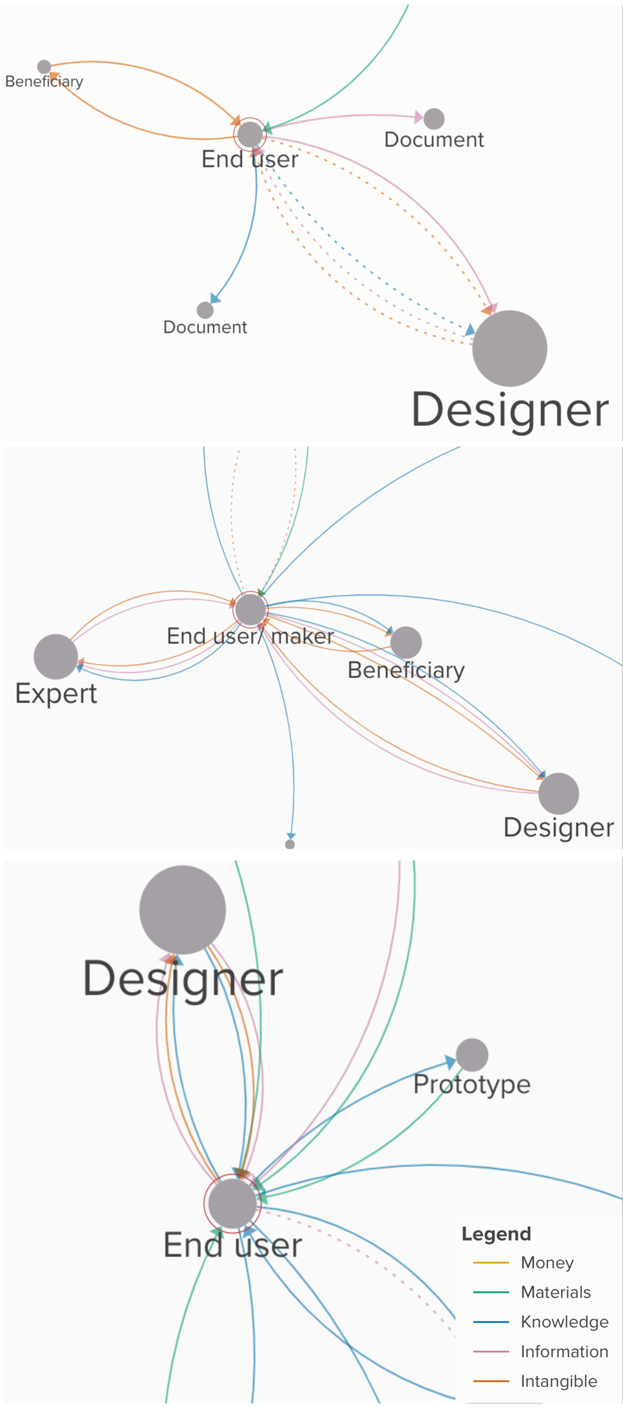
Case study	Knowledge	Information	Materials	Money	Intangible
1	0.00	0.02	0.00	0.00	1.00
2	0.14	0.16	0.00	0.00	1.00
3	0.18	0.14	0.00	0.00	1.00

Reciprocal interactions of knowledge occur exclusively between human actors in the networks. In CS1, there is no reciprocity of knowledge at all, whereas knowledge is reciprocated in 13% of interactions in CS2 and 18% of interactions in CS3. Filtering for information edge types, the reciprocity value is fairly low for CS1 (2%) in comparison with CS2 (16%) and CS3 (13%). In most cases, information is reciprocated between human actors, however this is not exclusively the case. For example, in CS2 the product requirements inform initial design sketches, which in turn shape the product requirements. In the network this interaction is thus visualised as a reciprocal information tie.

The differences between the reciprocal interactions in the case studies are particularly interesting when looking at the relationships between the lead designers and end users (see Figure 6.13). First, focusing on flows of information, it is observed that there is some information exchange between the designer and the end user in CS1. However, the end user is mainly sharing information with the designer. In other words, the clinicians at the health-post are important informants on the design problem. Specifically, they provide information to the designer about the lack of available otoscopes and the impact this has on their ability to deliver patient care. In CS1 there is limited information being directed from the designer to the end user, represented by an orange dotted line from the designer to the end user in Figure 6.13. The designer provides some updates on the product development of the otoscope to the clinician. However, most of the product development happens without their involvement and they have little visibility of the process. In contrast, in CS2 and CS3 there is mutual information exchange between the designers and end users. In CS2 the designers are frequently updating the technicians who manufacture the traditional prosthesis to gather direct feedback. In CS3, the designers frequently shared updates on the development of the suction pump machine with the nurses. Not simply for design validation, but because the nurses were considered to be members of the design team, albeit based at Kenyatta National Hospital and not MakerSpace Nairobi.

Second, focusing on knowledge exchange reveals some interesting points of comparison between the cases. In CS1, there is no knowledge exchange in the network. Rather, there is some limited knowledge being directed from the end user to the designer. In this example, the clinician is sharing their knowledge on how to treat patients with the designer. However, this is indicated as a weak relationship as the clinician has limited experience using the otoscope and thus shares limited expertise with the designer. In CS2, the transfer of knowledge between the end user to the designer is well-established and is continuous rather than a single event. What this means is that the technicians are sharing their expertise of how to produce the traditional leg prosthesis with the design team throughout the design process. In CS3, it is noted that knowledge is not just directed from the end user to the designer, but that it is reciprocated from the designer to the end user. The interactions underpinning this mutual exchange are the result of conscious decision making in the project. The nurses share their expertise of how to use the traditional suction pump machine with the designers. The designers also share their knowledge about the design process with the nurses, providing some training on design thinking and fast prototyping approaches. This establishes a knowledge exchange that results in mutual benefits for the participants and helps to foster equitable partnerships.

Third, intangible relationships are important reciprocal relationships throughout the networks. As described earlier, intangible relationships are implicitly bi-directional. However, it is worth noting the difference between the case studies. Notably, in CS1 intangible relationships are relatively weak between the designer and end user, in comparison with CS2 and CS3. It could be that this is partly a result of unfulfilled mutual exchanges of information and knowledge between the designer and end user. Another reason might be that in CS1, there are many more end users than in CS2 and CS3. As a result, it is difficult to establish deep connections with many individuals. Although this reduces dependency on any single end user, it means that these relationships are also less influential. One might think here about the maxim 'quality over quantity'. More broadly, it is worth noting who else end users establish reciprocal intangible relationships with in the networks. In CS1 and CS3, the participants identified that the end users exclusively exchange intangible values with the lead designer. However, in CS2 the end users exchange intangible values with multiple designers, beneficiaries and experts. It is observed that these interactions reinforce each other, resulting in strong relationships within the networks. Yet it is not to say that the more exchanges of intangible relationships, the better. There is the concern that this could create unwanted 'emotional labour' for end users and it could be impractical in reality. In general, the quality of relationships should be prioritised over a simple count of interactions.



CS1

- There is some information exchange between the designer and end user. However the end user is mainly sharing information with the designer.
- End user shares some knowledge with the designer.
- Overall, there is a weak relationship between the end user and designer.

CS2

- Information is exchanged between the designer and end user.
- End user shares knowledge with the designer.
- An intangible relationship is established between the end user and designer.

CS3

- Information is exchanged between the designer and the end user.
- Knowledge is exchanged between the designer and the end user.
- An intangible relationship is established between the end user and designer.

Figure 6.13 – Interactions between the designers and the end users

6.9.4 What is provided in exchange for money in the networks?

As mentioned earlier, exchanges of money are never reciprocal as other resources are being transferred in exchange. Table 6.12 shows the reciprocity scores of money and other tangible and intangible resources.

Table 6.12 – Reciprocity scores for money and other interactions

Case study	Money and materials	Money and knowledge	Money and information	Money and intangible values
1	0.07	0.04	0.02	0.53
2	0.11	0.15	0.17	0.79
3	0.07	0.15	0.12	0.65

Often money is being transferred in exchange for materials. Interestingly, money and intangible values have the highest reciprocity scores across the networks. As donors provide money to the implementers, intangible relationships are established between implementers and these donors. Sometimes, partners provide financial resources specifically in exchange for intangible values. For example, in CS2 Stratasys, an international 3D printing manufacturer, provides free 3D printing services for BETiC. Through this partnership, Stratasys benefit from the status of collaborating with a leading research institution on a technology project for social good. For them, this is directly related to their own Corporate Social Responsibility.

In some cases, money is also being exchanged for knowledge. For example, there is knowledge about the production of DF4D products being directed from the implementers to donors. Or there is knowledge being directed from individual designers to the implementing organisations that employ them. In other case studies, there are reciprocal exchanges of money and information. For example, information is directed from designers to implementers and from implementers to donors. It is important to recognise when money is being exchanged with other resources to reveal any potential sources of conflict. In these cases, it is not believed that there are particular sources of conflict. Nonetheless, DF4D projects should be mindful of the specific agendas of different stakeholders that may affect the project. Notably in the workshop with CS1, the different priorities of stakeholders were discussed. For example, it was put forward that the implementer (Field Ready) wanted to continue to serve its users, donors wanted to support 'innovative solutions', hospitals and health-posts wanted to provide patient-care and it was believed that the government wanted to invest in large scale infrastructure projects as opposed to technology-oriented projects.

6.9.5 How are digital fabrication tools positioned in the network?

The 3D printers in the network are positioned in fairly similar network structures in all the case studies. In CS1 and CS3, the designers and makers use their knowledge of 3D printing to operate the 3D printer. In contrast to popular reports that 3D printing can enable anyone to "*make anything, anywhere*" (Mandavilli, 2006), the participants underlined that 'experts' must be trained in 3D printing to operate both digital fabrication tools and digital design software. In CS2, these 'experts' are not just the designers and makers, but also the expert clinician who is involved in 3D printing. Machine producers also use the 3D printers to produce prototypes. Throughout the project, the machine producer AHA! also takes feedback from the design team and applies this to further develop their 3D printers.

In CS2, there is also a CNC milling machine involved in the DF4D project. Unlike the 3D printers, the CNC machine is not based at the implementer's facilities. This means that digital designs must be sent to a contracted fabricator who uses these designs and their knowledge to operate the CNC milling machine. In CS2, the CNC machine is used to cut a foam replica of the patient's stump, which provides a positive mould for forming the leg prosthesis. Reflecting on the networks, it is notable that the design team have less visibility over the CNC machine than the 3D printer, because of its position outside of the implementer's facility. One advantage of this approach is that the design team does not have to invest in expensive equipment. One the other hand, the designers lack the ability to intervene if problems arise. For example, they experienced some problems with the initial accuracy of the CNC machined foam parts. As they were not on-site at the CNC machining facility, it took some time to identify the root cause of this problem.

6.10 Summary of the main findings

This chapter has focused on mapping the networks of the case studies to build up an understanding of these complex socio-technical systems. In response to calls for more designerly ways of mapping networks, this chapter has presented Designet, a participatory visual toolkit that enables stakeholders to map their own networks. This study has shown that using Designet can provoke immediate insights on DfSS in DF4D projects. It provides a space for encounter that supports collective sensemaking and decision making. In addition, Designet provides a way of collecting rich data on the networks of DF4D projects which can be analysed post-factum. The Designet toolkit was used in three DF4D projects to facilitate the analysis of their networks.

This study has built on discussions in Chapter 4 which highlighted the importance of participatory design practices. It was previously put forward that DfSS necessitates a more participatory and democratic design practice (Bjögvinsson et al., 2012; Hillgren et al., 2011; Manzini, 2011; R. C. Smith & Iversen, 2018; Thorpe & Gamman, 2011) that supports the agency of local and connected actors (Caruso & Frankel, 2010; Kang, 2016; Manzini, 2015a). The analysis in this chapter has expanded our understanding of DfSS by explicating the relationships between different human and non-human actors; importantly, it has clarified *who* participates and *how* they participate in DF4D projects.

First, mapping the networks has shown that the presence and absence of specific actors can impact social sustainability. In particular, the presence of actors across the supply chain is believed to be a key driver of social sustainability, maximising impact in the wider ecosystem. For example, in CS2 the manufacturers of the digital fabrication tools and the material suppliers were also included in the network. The implementing organisation recognised the ability of the project to create widespread impact by establishing collaborations with different actors. The findings have also shown that the absence of key actors is a challenge for social sustainability. For example, the beneficiaries are not included at all in the networks in CS1 and CS3. In these cases, the beneficiaries are perceived as being fairly passive in the operation of both devices (the otoscope and suction pump machine). Mapping the networks made this oversight explicit in both cases. Furthermore, mapping the networks drew attention to the absence of potential influencers. For example, in CS2 it was noted that Bhagwan Mahavir Viklang Sahyata Samiti (BMVSS) was a missing actor in the process. BMVSS was the first charity to develop and manufacture the Jaipur Foot prosthesis in 1968. They remain the largest manufacturer of this prosthesis in India and are also responsible for training twenty-one other fabricators across the country. As such, they are a potentially very important hub for technology transfer and scaling-up impact. Using the Designet toolkit helped to illuminate this missing actor and triggered conversations about how they could be involved in the project.

Second, mapping the networks reveals the concern that some important actors have limited visibility over the network. Although the donors were important for sustaining the projects, it was found that they had little oversight of the design process in CS1 and CS2. They were often on the periphery of the networks and poorly connected to the main hubs of the network. In reality, this means that their engagement in the project is mainly as a provider of financial resources. Although some information and knowledge transfer takes place from the design team to the donor, this is fairly limited. In CS1 this meant that the donor was not necessarily highly invested in the DF4D project and the project struggled after they stopped funding the project. Mindful of the instability of donor funding in the aid sector, it is recommended that the donor should be positioned such that they have high visibility of the network and that they are positioned as partners, not just as suppliers of financial resources.

Third, mapping the networks helped to identify missing or broken links that limit social sustainability. In some cases, these broken interactions became apparent to the participants in the workshops. For example, in CS1 the participants noted a missing link between the lead designer and the project documentation, as they had not formally recorded feedback from the end users. This prompted a collective agreement on best practices for collecting feedback in the future. In other cases, the network analysis provided another perspective to reveal these broken links. For example, comparison of the three networks made it clear that deep engagement with a limited number of homogeneous actors is preferable to superficial engagement with many homogeneous actors. Specifically, the network analysis underlined the importance of establishing equitable relationships between the design team and the end users. Instead of positioning the end users as the recipients of physical products or viewing them as 'stores' of information to be called upon, they should be given the opportunity to meaningfully engage in the design process. The network analysis has highlighted that the most promising networks facilitate reciprocity and mutual exchange of both knowledge and information between the designers and the end users. It has thus helped to reveal who is disadvantaged by the current system and suggested how remedial action might be taken.

Finally, mapping the network has helped to explore how potential stakeholder conflicts might impact social sustainability. In each of the workshops, the participants spent time reflecting on which actors initiate, drive and benefit from DF4D projects. It became clear that the actor who initiates the project often has priority in setting out who directs and benefits from the projects. In CS1, the initiator was the implementer Field Ready. In CS2, the initiator was the local charity, RNCT who produces the traditional prosthetic. In CS3, the donor Concern Worldwide initiated the project after reflecting on the needs of several hospitals in Kenya. The reality of 'user-driven' projects was discussed at large. Although all of the participants agreed that the DF4D projects responded to a real user-need, they shared the belief that 'user-driven' projects (i.e. projects initiated by the users themselves) are not the norm in the aid sector. In reality, beneficiaries in the aid sector often lack the social, human or financial resources to initiate projects. Of course there are exceptions and at the time of visiting BETiC, a 'user-driven' non-DF4D project was in fact being developed by BETiC with an entrepreneur, Aneesh Karma, a polio-affected person who had designed a comfortable leg brace to assist people affected by polio. However, it was largely felt that this was not realistic for the majority of projects.

Regardless, the participants recognised the importance of reviewing who is driving and benefiting from the DF4D project on an on-going basis. Related to this discussion, the difference between technology-centred versus people-centred design emerged as an important conversation during the workshops. In general the participants felt that their approaches were people-centred. In fact, participants in CS1 often criticised other types of aid projects for not being sufficiently user centred: "*It's surprising how little aid organisations actually ask their beneficiaries what their problems are. That was a mind-blower for me when I first arrived in Nepal*" (CS1-01). Comparing these views with the networks for CS1 revealed a disparity. As discussed earlier, the digital fabrication tool (the 3D printer) in CS1 is a more influential actor than any of the end users. Network analysis is thus a valuable tool for revealing conflicts between what people think is happening and what is happening in reality. Thus, it can shine a spotlight on potentially problematic behaviours before their impact has been fully realised.

6.10.1 Theoretical implications

This study has significantly enriched our understanding of DfSS in DF4D. Earlier it was put forward that DfSS necessitates a more participatory and democratic design practice that supports the agency of local and connected actors. This chapter has helped to clarify these broad claims, by identifying the different ways that actors interact in DF4D projects. More specifically, it has identified an ontology for comparing the networks of these projects. This included an ontology of the different types of interaction (and de facto participation) that take place in DF4D.

Whilst it was previously understood that participatory design practices would advance DfSS, this study has shown that not all participation is equal. In some cases, actors are present in the network, that is they participate yet they remain passive, therefore undermining DfSS. Reciprocity was specifically highlighted as an important network metric that can reveal (in)equitable relationships. This study has gone beyond existing work on participatory design, which differentiates between empowering and tokenistic forms of participation (Arnstein, 1969; Cornwall, 2008), to show how specific types of participation can reinforce systems of (in)equality. By classifying these types of interactions (as knowledge, information, materials, money and intangible values), as well explicating their strength and direction, this study has provided a way to measure the 'depth' of participation, which Bratteteig & Wagner (2016) note is currently lacking in participatory design literature.

More broadly, using ANT as a methodological guide has deepened our understanding of DF4D projects as socio-technical systems. The inclusion of non-human actors has proved to be a valuable way of interrogating the relationships in DF4D projects and it has illuminated some interesting insights around technology-centred versus people-centred projects in relation to DfSS.

6.10.2 Practical implications

Overall, this chapter has attempted to provide a more emancipatory way of collecting network data and to reveal who is being disadvantaged by the current network structures. This chapter has enriched earlier discussions on DfSS by making explicit the types of interactions that take place in DF4D projects. It has also revealed the structures of agency and power that underlie these projects. Considering the premise that power does not exist per se but that it is manifested through the interactions of a network (Latour, 2005 p. 66), it is proposed that Designet can serve as an intervention in DF4D projects that seeks to dismantle and rearrange networks. It can tackle the inequitable relationships that are a barrier to social sustainability; it helps to identify the imbalances between actors and tackle them head on.

This study has also elaborated on the view that Designet is a boundary object, which helps to facilitate collective understanding and communication. Taking this one step further, it is suggested that using Designet can actually create a de-risked space to explore new design possibilities. In other words, it offers a protected environment in which "risk taking" can become acceptable for the actors involved. These kinds of protected environments can help to break free of problematic and conventional thinking, however they are often not compatible with the urgency and complexity of DF4D projects. Designet thus opens up a much-needed hypothetical space for actors to explore different ways of reorganising the networks to advance social sustainability.

6.10.3 Limitations

This chapter has significantly advanced our understanding of DfSS in DF4D projects. However, there are some limitations that may affect these findings. First, this study recognises that any network representation will never be fully exhaustive. As Venturini (2012) explains "*sometimes content remains invisible because they are too marginal or ephemeral, sometimes because they are concealed by their authors and sometimes they are just forgotten*." Morrison & Dearden (2013) also warn that visual artefacts can draw attention to certain aspects whilst obscuring others. In an attempt to mitigate this, the researcher took time to consider other case study data, including interviews and reports to validate that the networks mapped in the workshops were as detailed and accurate as possible.

Second, it was difficult to arrange the participation of different actors at the workshops. In CS3 only two people participated in the workshop, which may affect the validity of this network map. Moreover, only members of the design team participated. Despite striving to give a voice to the actors that might not normally be involved in the decision making, the failure to convene these groups undermined these ambitions. In defence, the researcher points out that despite the absence of these groups, the networks still revealed that these absent stakeholders were often on the peripheries of the networks. In addition, the networks were able to illuminate the asymmetry of these relationships, thus inviting much-needed reflection from the design teams.

Finally, it is important to remember that the networks shown in this study only represent a specific moment in time. Latour (2005, p. 201) points out that mapping the actor-network will never be the same twice: "*You will never get the same count no matter how many times you do the counting because every time different agents will be made visible while others will have become dormant*." This study suggests that the networks should be owned by the participants so that they can be updated and referred to throughout the DF4D projects. Kumu was partly selected because it provides an open platform to facilitate this. However, the actual practicalities of what this looks like requires further exploration. Overall, this study is mindful that visualisations are only provisional representations of reality, which are "*useful for guiding further study, but are not susceptible to proof*" (Oreskes et al., 1994, p. 644).

6.11 Summary

This chapter has adopted a critical systems perspective to explore DfSS in DF4D. It put forward that DF4D projects are complex socio-technical systems and that network analysis offers a way to better understand these systems. ANT was identified as a suitable network approach to investigate DF4D projects. Responding to calls for more designerly ways of collecting data about networks, an initial participatory toolkit, Designet, was developed that allows actor to map the networks of their own DF4D projects. Considering the underlying emancipatory agenda of this research, it was considered how Designet could not only serve as a means for data collection, but could also act as 'boundary object', a temporary bridge to create shared meaning and advance DfSS. Designet was used with three case studies and the results have been presented in this chapter. Kumu, a web-based platform was also used to further digitally represent and analyse these networks. Quantitative and qualitative analysis helped to clarify and expand on earlier claims that DfSS demands more participatory and connected design practices. Notably, the findings indicate that the nature of an actor's participation is more important than participation itself; certain types of participation may actually reinforce systems of inequality. Overall, this chapter suggests that Designet is a promising initial toolkit that can serve as an intervention in ongoing DF4D projects. Designet creates an opportunity to dismantle and rearrange existing networks, thus providing a de-risked space in which to explore socially sustainable alternatives. The following chapter will compare the results of this chapter with the findings from the analytical study. It will discuss the implications of the main study more broadly.

Chapter 7 Discussion

7.1 Introduction

This thesis started by introducing the growing phenomenon of DF4D. Despite excitement about the transformative potential of DF4D, this study raised initial concerns that many technology projects in the aid sector have struggled to create lasting impact. In Chapter 3, the exploratory study found that contrary to popular reports which focus on solely positive accounts, there seems to be more failure than success in DF4D. It also confirmed that social sustainability is largely overlooked in DF4D projects and that designers are not sufficiently equipped to remedy this. Following this, it was decided to further investigate how design can promote social sustainability. Chapter 4 derived several key themes of DfSS from the literature, providing a theoretical foundation to this work. The main study then diverged in two different directions. Chapter 5 took an analytical approach to investigate DfSS in DF4D projects. It built on the key themes of DfSS and presented a detailed case study of three healthcare DF4D projects in order to develop a practical framework for DfSS in DF4D. Chapter 6, on the other hand, took a critical systems approach. ANT was selected as a methodological framing to investigate the networks of DF4D projects. Designet, an initial visual participatory toolkit was developed that allows actors to map the networks of their own projects. The toolkit was used to collect data about the networks of the three case studies. This chapter compares and reflects on the main findings of this thesis and speculates more broadly on designing a transition to social sustainability.

The first part of this chapter discusses the results of the main findings. It compares the analytical and critical systems approaches to show that they provide complementary insights into DfSS in DF4D. It is put forward that both approaches are necessary but neither is sufficient alone. The second part of the chapter is more speculative and situates the findings of this thesis within the wider context. It takes a step back to reflect on how the disparate DF4D projects examined in this thesis can more broadly influence the transition to social sustainability in the humanitarian and development sector. The Multi-Level Perspective framework is introduced to help guide this discussion. This reflection also accounts for the contextual differences between the main case studies which up until now have not been discussed at length. The final part of the chapter returns to the role of design in promoting social sustainability. It builds on previous arguments that design is a strategic lever for bringing about social sustainability. Finally, it also reflects on how DfSS fits within the wider discourse on sustainability.

7.2 Comparing the analytical and systems approaches

This thesis is grounded in a pragmatic philosophy which does not view the world from a fixed ontological and epistemological position. Instead it embraces a plurality of worlds, or what Escobar (2018) calls the pluriverse, to seek a richer understanding. Accepting this as a starting point allowed the main study to be framed in two different ways: Chapter 5 took an analytical approach; and, Chapter 6 adopted a systems approach.

The analytical approach is based on the idea that any complex system can be reduced into its individual parts. Analysis is derived from the Greek word 'analusis', 'ana' meaning up and 'lusis' meaning 'loosening' or 'dissolution'. Thus, 'analusis' literally means a 'loosening up' or 'dissolution' (Pikas, 2019). In other words, it seeks to break down complex problems into parts that can be studied separately. Advocates of this approach argue that it provides an important way of simplifying and understanding systems that would otherwise be unmanageable (McCleod, 2008). For this reason, it has proven to be a useful tool in the development of human society (Linderman, 2012). Critics on the other hand, argue that analytical approaches fail to recognise the deeply interconnected reality of different parts in a system. They call for a systems approach which instead of looking at parts in isolation, aims to synthesise the whole (Meadows, 2008). This perspective pays close attention to the interactions between elements (Sterman, 2000) and also helps to identify emergent behaviour that could not be predicted by the properties of individual parts (Nicolis & Nicolis, 2012).

In recent years, systems thinking has become an increasingly popular way of dealing with complex societal problems (da Costa Junior et al., 2019). Analytical approaches, on the other hand, have been largely disregarded for their reductionist way of handling problems (Adam & de Savigny, 2012; Zink, 2014). Yet, without a basic understanding of the parts of a system, it may be very difficult to apply a systems approach. Focusing solely on a systems approach can also be impractical when connections are unclear or difficult to measure (McCleod, 2008; Tuominen, 2014). In fact the initial proponents of systems thinking did not intend for it to entirely replace analytical approaches (Meadows, 2008). Rather they understood analytical and systems thinking as a complementary way of viewing the world. Despite this, very few studies look at integrating both approaches, and it is this ambition that has guided the main study.

7.2.1 Overview of the main study

The main study set out to investigate how design can promote social sustainability in DF4D. It conducted three case studies of healthcare projects in DF4D, with the main focus of analysis at the project-level. Table 7.1 summarises the two different approaches taken in Chapters 5 and 6.

Chapter 5 applied analytical thinking and was motivated by a desire to reduce complexity. This resulted in a framework to support DfSS in DF4D projects. The DfSS framework identified sixteen factors, which are broadly categorised as either product, process or paradigm factors. The framework encourages designers to move beyond just thinking about product attributes, which have traditionally dominated sustainable design approaches. Instead, the designer must consider the integration of process and paradigm factors to maximise social sustainability. The findings in this chapter highlighted that DfSS necessitates more systems-focused and radical solutions. It analysed the case studies using the framework to demonstrate its value.

Chapter 6 adopted a critical systems perspective in order to embrace the complexity of DF4D projects. This led to an exploration of DF4D projects using ANT as a methodological guide. Designet was developed as a participatory toolkit that could serve to: (1) collect data about the networks of DF4D projects, and (2) facilitate sensemaking and decision making among stakeholders. This chapter paid particular attention to the DfSS themes of participation, agency and connectedness. It clarified and enriched these concepts by revealing the networks of the case studies. It was also put forward that Designet can offer the possibility to dismantle and rearrange networks, thus enabling a de-risked space in which to explore social sustainability in DF4D projects.

Table 7.1 – Comparison of the analytical and critical systems approaches in the main study

	Chapter 5	Chapter 6
Object of enquiry	DF4D project	DF4D project
Way of enquiry	Analytical thinking	Critical systems thinking
Rationale	Seeks simplicity	Embraces complexity
Main approach	Analysing the key principles of DfSS in DF4D	Mapping the networks of DF4D projects
Methodology	Thematic coding	Actor-Network Theory
Thematic focus	Broad	Narrow (participation, agency and connectedness)
Main outcome	DfSS in DF4D framework (analysis of three case studies in the healthcare sector)	Designet toolkit (analysis of three case studies in the healthcare sector)

7.2.2 Differences between the framework and toolkit

Before discussing the main findings at length it would be worth noting the key differences between the DfSS for DF4D framework (in Chapter 5) and the Designet toolkit (in Chapter 6). This section expands on the differences highlighted in Table 7.2.

First, the underlying paradigms of the framework and toolkit vary. Whilst the framework sets out the constituent parts of DfSS and is thus normative, Designet allows for a more interpretative version of DfSS. Normative studies offer perspectives on how things ought to be and their role in sustainability research has become more widely recognised in recent years (Schneider et al., 2019). Normative work is often at the heart of studies on sustainable development. For example, Morris' (1980) Physical Quality of Life Index and the United Nations' Human Development Index (Stanton, 2007) are both examples of multi-dimensional indicators that have attempted to challenge Gross National Product as a way of defining national welfare. Interpretive studies on the other hand resist a priori assumptions, and instead seek to build up understandings about the behaviours of systems. Whilst using Designet, participants are invited to construct their own view of the DF4D projects. In doing so, they navigate the complex and interconnected realities of these projects. Participants are prompted to explore how their actions relate to social sustainability, without any prescriptive guidance about DfSS. This gives way for a much more dialogical exploration of DfSS between the different stakeholders.

The framework and the toolkit also provide distinct lenses with which to analyse DfSS in DF4D. The framework is naturally suited to problem solving; it helps designers to find solutions to the complex problems at hand. This very much tallies with the view that design is a problem-solving activity (Cross, 2001). The toolkit on the other hand, facilitates sensemaking; it allows actors to build a shared understanding and identify the meaning of their work. The importance of sensemaking in design is also well-established (e.g. Forester, 1985), with Krippendorff (1989) even arguing a strong case that design *is* the making sense of things (sensemaking). Furthermore, the toolkit actively seeks to uncover controversies or conflicting views among participants, whereas the framework seeks consensus. Whilst consensus is an important pre-requisite for decision making, conflict has also been identified as a key driver of creativity and innovation in design teams (Badke-Schaub et al., 2010). Pairing the two approaches could thus help to navigate this space and unlock new opportunities for DfSS.

Finally, it should also be noted that the framework and toolkit are intended to be used differently. Whilst the framework is created for the expert designer/decision-maker and can be used individually, the toolkit demands the participation of a wide range of actors. It therefore allows for diffuse decision-making by non-expert designers (Manzini, 2015b). The framework also seems to offer the most value in the early planning stage or evaluation stages of the project. It can assist designers to make decisions about the project, and to evaluate the extent to which design is being used to promote social sustainability. The toolkit provides a complementary approach, offering a way of investigating DfSS during an ongoing project. It gives actors an opportunity to identify and explore alternative network configurations, to advance social sustainability. In this sense, the mapping process is both a means and an end. The final network representations are valuable for further analysis, however the process of convening actors and mapping the network is also important for creating new insights on DfSS. The framework can be viewed as more of a means to an end; the process of using it does not substantially advance DfSS, however the final evaluation is useful for guiding practitioners.

Table 7.2 – Differences between the DfSS in DF4D framework and the Designet toolkit

DfSS for DF4D framework (Chapter 5)	**Designet toolkit (Chapter 6)**
Normative (to be)	Interpretative (as is)
Problem solving	Sensemaking
Consensus	Controversies
Expert	Diffuse
Individual	Group
Early planning and evaluation	During ongoing project
Means to an end	Means and an end

7.2.3 Comparison of the main findings

So far the key differences between Chapters 5 and 6, and their outcomes have been discussed. Despite the fact that the studies are grounded in different modes of enquiry, they contribute to some shared areas of knowledge. Table 7.3 summarises the complementary insights from the main study, which have helped to conceptually develop DfSS. The following section will discuss these findings and identify their linkages to relevant theories.

First, the findings underline that DfSS in DF4D must include a greater emphasis on capabilities, not simply the provision of products. The DfSS framework in Chapter 5 identify multiple criteria which necessitate the development of local capabilities. For example, if local manufacture, control and repair are to go hand in hand with advancement and empowerment, then capability building is a fundamental activity. Chapter 6 adds to this discourse on capabilities by focusing on the flows of resources in the network. The Oxford English Dictionary describes capabilities as the power or ability to do something. Thus, identifying the resources that actors interact with reveals how their capabilities are manifested. It also brings into question the (dis)parity between the actual interactions in the network and the opportunities that exist to realise these interactions. In other words, how do actors actually participate with respects to their capability to participate.

More broadly, these findings enrich existing knowledge on human capital theory and the capability approach. In its simplest form, human capital theory suggests that education and the development of human capital is a fundamental driver of productive societies (G. S. Becker, 1993). The capability approach was pioneered by the development practitioner Amartya Sen, and puts forward that human capabilities are central to poverty alleviation (Sen, 1980, 1985, 1999, 2000). According to Sen poverty is multi-dimensional and is caused by exclusion from:

> "*a livelihood; secure, permanent employment; earnings; property, credit, or land; housing; minimal or prevailing consumption levels; education, skills, and cultural capital; the welfare state; citizenship and legal equality; democratic participation; public goods; the nation or the dominant race; family and sociability; humanity, respect, fulfilment and understanding.*"
> (Sen, 2000)

In this sense, poverty does not just refer to a lack of financial resources, but a lack of social sustainability (according to the themes of social sustainability identified in Chapter 3). Sen argues that the capability approach refocuses attention on the ends instead of the means; it looks to expand what people can do, not just increase the resources that they have available to them. In Sen's (2013) keynote speech to the International Conference on Transition to Sustainability he puts forward a contrast between perspectives on need fulfilment and capabilities. He raises the concern that only focusing on needs will lead to a downward adaption of care:

> "*people who are used to living in a persistent state of undernourishment, illiteracy and lack of basic healthcare may come to think of nourishment or school education or medical attention as a luxury, rather than as a 'need', so that even if we go by their own self-perception of needs, we may take an unjustly limited view of their deprivation."* (Sen, 2013, p. 11)

The main findings in this thesis echo the importance of the capability approach. Specifically, to progress DfSS in DF4D, local communities must develop the capabilities to design, manufacture, repair and maintain DF4D projects. However this study does not completely disregard the importance of needs. Rather the findings call for appropriate need fulfilment that considers the broader context, at the same time acknowledging that this relies upon the development of human capabilities.

Second, the findings suggest that DfSS in DF4D requires a broad shift from exogenous to endogenous solutions. As noted in the introduction, the aid sector has a long history of relying on imported resources. The findings make clear that digital fabrication has an important role to play in bringing about more endogenous solutions. Chapter 5 shows that endogenous development is key to satisfying paradigm-related factors such as advancement, empowerment and systemic change. In part, these findings reinforce literature on sustainable livelihoods, which advocates for the alleviation of poverty by enabling people to earn a living (Roberts Chambers & Conway, 1991; Norton et al., 2001). Chapter 6 investigates exogenous/endogenous relationships in a different way, by including 'places' as nodes in the network. This pays attention to the geospatial dimensions and transnational linkages that take place within DF4D projects, and encourages participants to reflect on how these can influence the project at large. Importantly the findings in this thesis clarify that endogenous practices do not imply that change is only at a 'local' or community level. Instead, it is necessary to mobilise a system of actors to tackle the root causes of social un-sustainability.

The findings also present another angle on postcolonial and dependency theory. Dependency theorists argue that the post-colonial relationships between 'centre' high-income states and 'periphery' low-income states trap the South in poverty. In this system, the core countries dominate in terms of technology and capital intensive industries, whereas the periphery countries provide resource extraction and cheap labour (Dos Santos, 1970; Frank, 1967). As Vernengo (2006) explains:

> "*The centre countries controlled technology and the systems for generating technology. Foreign capital could not solve the problem, since it only led to limited transmission of technology, but not the process of innovation itself.*"

To date, the delivery of products in the aid sector is still predicated on the 'Diffusion of Innovation' (Rogers, 1983) which mainly relies on the linear flow of technologies from the Global North to the Global South. The findings in this thesis support calls for an alternative model which builds on endogenous resources. The evidence shows that traditional technology transfer mechanisms are not effective at creating social sustainability, and more pressingly that endogenous design is fundamental to disrupting the root causes of underdevelopment (Rodney, 2018). DF4D presents a unique opportunity to disrupt existing paradigms of production, and to enable the growth of endogenous capabilities. However, without a conscious investment in local capabilities, DF4D will simply serve to create another market for the diffusion of technology from the North to South.

Third, the findings make clear that DfSS requires a transformation in the identity of actors from passive to active participants. Whilst Chapter 5 revealed the broad importance of collaboration, Chapter 6 provided a more thorough investigation of participation and highlighted the need to 'switch on' actors in the network. It focused on how different types of resources are transferred to/from actors, and found that reciprocity was a useful way of measuring (in)equality in the networks. It also provided a valuable way of interrogating broad concepts such as participation, agency and connectedness by identifying the position of different actors in the network and looking at the overall shape of the network. This analysis highlighted the importance of reciprocal information and knowledge flows between human actors, particularly between designers, experts and users. It also questioned the neutrality of certain relationships, where it highlighted that money was being exchanged for other resources such as intangible values. This provided a useful lens with which to explore some of the power dynamics within the networks of DF4D projects, whereby power was viewed as a relational or diffused concept, according to Foucault's

(1979, p. 307) conceptualisation of power as: "*not a network of forces, … [but] a strategic distribution of elements of different natures and levels.*"

Although participatory approaches are well-recognised in development studies (see the Participatory Rural Approach by Archer & Cottingham (1996) and Chambers (1997); and, the Community-based participatory approach in Israel et al. (2010)), this study goes much further to investigate the nature of participation itself. Active/passive is not a binary classification, but a continuum that is characterised by different types of interactions, which are both directed and weighted, for different actors. Chapter 6 also enriched our understanding of participation by showing that certain types of passive participation can actually produce mechanisms for the disempowerment of actors, under the guise of participatory approaches. This helped to question the assumption that participation will naturally lead to the empowerment of actors. It therefore drew attention to the need for more active forms of participation that can reinforce the impact of endogenous and capability-based approaches.

Fourth, the findings make clear that DfSS in DF4D should seek open-ended solutions instead of quick fixes. Chapter 5 advocated for a long-term approach that moves beyond deploying products, but instead integrates them within a wider system of change. It argued the case for a broader consideration of what works that is not simply focused on the delivery of artefacts, but thinks about how to maximise impact across the entire project lifecycle. Chapter 6 also shifted the agenda away from quick fixes by framing DF4D projects as complex socio-technical systems. Mapping the networks of these projects helped practitioners to build up a rich understanding of their systems and opened up the problem space. This is a crucial step in broadening thinking from narrow problem-solution spaces that are focused predominately on quick technical fixes. It was also found that mapping the networks of DF4D projects provided a safe space in which actors could negotiate different future scenarios. This confirmed the need for actors to be given the opportunity to explore open-ended solutions in risk-free, protected environments.

These findings echo calls for the integration of systems and holistic design into aid sector projects (Bowman et al., 2015; Santos & Wauben, 2014). Santos (2015) puts forward that systems design is important for developing a holistic view of interventions which can accommodate long-term and decentralised approaches. In general, systems design recognises the complex and interrelated nature of the world, and takes account of the broader context at large (Meadows, 2008). Chapters 5 and 6 contribute to this dialogue by providing practical tools to assist organisations to embrace systems-focused solutions. Although the benefits of systems thinking are recognised in the aid sector, one of the main barriers to its adoption is the belief that systems approaches are inaccessible and impractical (Levine, 2016). This main study has thus addressed these concerns by providing two complementary ways of exploring DfSS. By aligning the goals of DF4D projects with social sustainability, it has shown that systems-focused solutions are not just desirable, but that they are fundamental. The question for organisations then becomes not 'how can we afford to take a systems approach?' but 'how can we afford to *not* take a systems approach?'

Finally, the main study suggests that DfSS in DF4D requires a shift from one-off to scalable interventions. The DfSS framework in Chapter 5 drew attention to the importance of scalability and systemic change to expand the impact of single interventions. According to the practitioners, DfSS requires more than just isolated initiatives. Their views are a reminder of Manzini's (2014) call for "*constellations of design initiatives geared toward making social innovation more probable, effective, long-lasting, and apt to spread*". Whilst the findings draw attention to this imperative, they also reveal that large scale action is absent at present. It can be said that the case studies operate as local discontinuities. In other words, they are isolated and local initiatives. Despite their individual transformative potential, they remain far from a network of collaborative projects. Chapter 6's efforts to map the networks of DF4D projects provided an opportunity to identify possible linkages within the ecosystem, however it is clear that further support is needed in this domain. Existing theories and approaches in development studies are notably absent in this respect. Perhaps this is not surprising as interventions in the aid sector are often criticised for failing to move beyond the scale of community-based initiatives (Begovic et al., 2017). Indeed, the scalability of interventions has been a long running concern of technology initiatives in the aid sector (Elhra, 2018). To investigate this further, this chapter moves on to the following part of this discussion. Specifically, it draws on literature from sustainability transitions to situate the findings of this study in the broader context and to reflect on how a widespread transition to social sustainability might be designed.

Table 7.3 – Complementary insights from the main findings

Shifting agenda from…			**Chapter 5** ***Analytical approach***	**Chapter 6** ***Critical systems approach***	**Selected literature on** **relevant theories/approaches**
Products	←→	Capabilities	Suggests that the development of local capabilities will help to break the cycle of dependency in the aid sector. Capability building is central to the advancement and empowerment of local communities.	Pays attention to actors' capabilities by focusing on the flows of resources in the network. Helps to identify how capabilities are concentrated or diffused in DF4D projects.	The Capability Approach (Sen, 1980, 1985, 1999, 2000; Sen & Drèze, 1989) Human-capital theory (G. S. Becker, 1994)
Exogenous	←→	Endogenous	Local manufacture, control and repair are important for project longevity. Emphasis on the need for contextually suitable solutions. Endogenous solutions key to fulfilling paradigm-related factors.	Introduces 'place' as an actor type, making stakeholders sensitive to where the project takes place. Prompts reflection on the project trigger (exogenous versus endogenous).	Sustainable livelihoods (DFID, 2001) Dependency theory (Alvin, 1990; Vernengo, 2006) Post-colonialism (Escobar, 2012a, 2018; Said, 1978)
Passive actors	←→	Active actors	Does not explicitly address discourse on passive/active actors, however underlines the importance of collaboration with a range of stakeholders.	Highlights active/passive engagement by revealing how different types of resources are transferred to/from individual actors. Reciprocity is highlighted as key metric to understand engagement. The position of individual actors and the shape of the network highlights how actors are (un)empowered.	Participatory Rural Appraisal (Archer & Cottingham, 1996; Robert Chambers, 1997) Community based participatory approach (Israel et al., 2010; Minkler & Wallerstein, 2003; Wallerstein et al., 2003)
Quick fixes	←→	Open-ended solutions	Emphasis on the integration of product, process and paradigm factors calls for more long-term solutions that are not simply about deploying a product but rather integrate products within a wider system of change.	Frames DF4D projects as ongoing initiatives, and allows actors to envision different possible future scenarios. Provides a safe space for critical dialogue and acceptance of potential failure.	Holism (S. Bell & Morse, 2005) Systems design (Blizzard & Klotz, 2012; Charnley et al., 2011)
One-off projects	←→	Scalable interventions	Recognises the need for scalable and systemic impact.	Provides an opportunity to identify linkages with other actors/ institutions, however the main focus is inter-project (at the one-off project level).	Sustainability transitions (Geels, 2002, 2004; Markard et al., 2012)

7.3 Designing a transition to social sustainability

So far, this thesis has focused on how design can promote social sustainability in DF4D, at the individual project-level. However, the main study has suggested that social sustainability requires a more widespread constellation of initiatives that can bring about systemic change. This part of the chapter reflects on the main findings and draws on literature from sustainability transitions to consider the transformative potential of DF4D and the role of design in promoting a widespread transition to social sustainability. To begin with, literature on sustainability transitions and the Multi-Level Perspective will be introduced. This section will use this framing to reflect on the main case studies and position the findings in the broader context. It will speculate on the potential for DfSS in DF4D to support a widespread transformation to social sustainability in the aid sector. At this point the researcher departs from the earlier discussion which is largely grounded in evidence from the main study, to take a more reflective position that considers the broader implications of this study.

7.3.1 Background on sustainability transitions

Simply put, a transition is a change from one state to another. The field of sustainability transitions emerged in the 1990s to tackle complex sustainability challenges (Loorbach et al., 2017). It attempts to understand the long-term changes that are needed to address complex societal problems (Rotmans et al., 2001). A core belief in sustainability transitions is that these *"problems cannot be addressed by incremental improvements and technological fixes, but require radical shifts to new kinds of socio-technical systems"* (Köhler et al., 2019). A popular analytical framework in sustainability transitions is the Multi-Level Perspective (MLP), which was initially put forward by Rip & Kemp (1998) and later expanded by (Geels, 2002, 2004). This model shows that the unfolding dynamic of a socio-technical transition depends on the reciprocal interactions between the micro (niche), meso (regime) and macro (landscape) levels. Figures 7.1 and 7.2 show the MLP model adapted from Geels (2002) and (Loorbach et al., 2017).

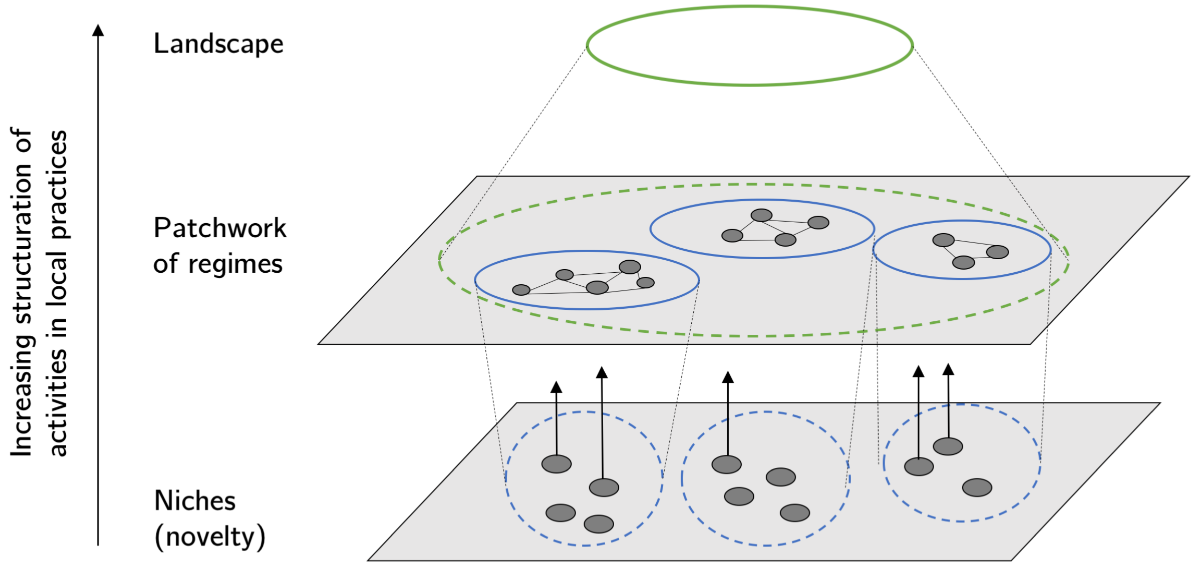


Figure 7.1 – MLP model showing linkages between the landscape, socio-technical regime and niche levels adapted from Geels (2002) and Loorbach et al. (2017)

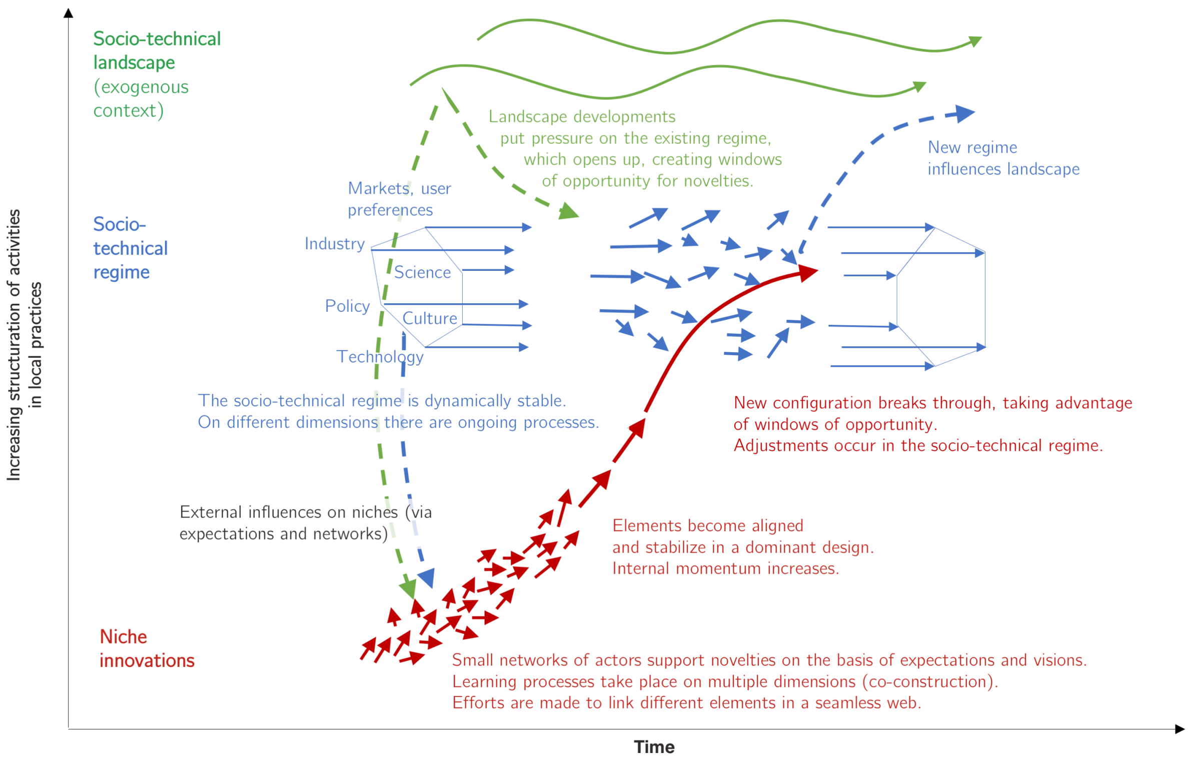


Figure 7.2 – MLP model showing transitions pathways between landscape, regime and niche levels adapted from Geels (2002) and Loorbach et al. (2017)

The *regime* is a fundamental concept in transitions, which represents the dominant and stable configuration of the socio-technical system[16] (Geels & Schot, 2007; Loorbach et al., 2017; A. Smith & Raven, 2012). It represents the formal and informal structures which constitute the established way of doing and thinking about things. Socio-technical regimes can be thought of as having three main dimensions (Geels, 2005): (i) material and technical elements; (ii) networks of actors; and, (iii) regulative, normative and cognitive rules (that shape institutions). The interaction of these three dimensions is responsible for the lock-in of the established socio-technical regime (Geels, 2002; Unruh, 2000). The MLP puts forward that this path dependency will continue until there is sufficient destabilisation of the regime from the landscape and niche levels (Geels & Schot, 2007).

The *landscape* is the exogenous environment to the socio-technical regime which is shaped by slow-changing global trends that include macro-economics, politics, technology adoption, cultural values and ecological shifts (Geels, 2004). The landscape either conditions the established regime or destabilises it, and indeed it is possible for the regime to influence the landscape (Grin et al., 2010). *Niches* are protected environments where novelties can emerge away from the constraints of existing regimes (Kemp et al., 1998; Raven, 2007). They provide spaces to incubate new ideas through sustainability experiments, which Berkhout et al. (2009) describe as "*initiatives that embody a highly novel socio-technical configuration likely to lead to substantial sustainability gains."* Experiments provide important seeds of change (Kemp et al., 1998) that support niche development and can eventually influence the incumbent regime (Raven, 2007).

According to Schot & Geels (2008) the viability of niches is influenced by three internal processes. First, the shaping and alignment of expectations is necessary among niche-level actors. Establishing similar visions, belief and interests is important for niche development, and failure to do so may result in hype-disappointment cycles (Bakker & Budde, 2012). Second, niches rely on the formation of social actor networks that provide complementary resources for stimulating niche development. Third, learning processes are essential for testing and providing feedback on niche-level experiments. This also requires a deep understanding of the incumbent regime and landscape.

[16] Note that regime here refers to an analytical level, and does not invoke the political definition of an authoritarian government that is used in common speech.

It stands that any widespread transformation depends upon the reconfiguration of the established socio-technical regime. Here the MLP offers a starting point for explaining the power contestations that can occur between the incumbent regime, and the landscape and niche levels (Avelino, 2011; Geels & Schot, 2007). Niches play an important role in the development of alternative regimes, as they help to nurture experiments which counter the mainstream agenda (Kemp et al., 1998). Yet it is widely believed that these niches are an insufficient force for transforming the regime (Berkhout et al., 2009). What is needed then is sufficient pressure from the landscape to also destabilise the regime (Geels & Schot, 2007). The combination of these forces is required such that the regime experiences problems and collapses, whilst a window of opportunity exists for the niche to become empowered (A. Smith & Raven, 2012). As A. Smith (2007) explains, any transformation depends upon *"regime actors los[ing] faith in the current system and defect[ing]".*

7.3.1.1 Sustainability transitions in the Global South

Before proceeding it is worth alerting the reader to some of the applications and criticisms of the field of sustainability transitions in the Global South. Research on sustainability transitions originally emerged from technology studies in Europe (mainly in the UK and the Netherlands). Although it was initially used to describe the historical transformation of socio-technical systems in industries such as energy, mobility and water (Loorbach et al., 2017), the field has grown substantially in recent years and a number of studies have been dedicated to investigating sustainability transitions in the Global South (U. E. Hansen et al., 2018; Wieczorek, 2018). For example, Nygaard & Bolwig (2018) investigated the trajectories of biofuel production in Ghana; Sixt et al. (2018) explored water harvesting practices in Jordan; Onsongo & Schot (2017) looked at a mobile-phone based money solution in Kenya; and, van Welie & Romijn (2018) looked at the provision of urban sanitation in Kenya. More specifically, the value of sustainability transitions in research on the aid sector has been recognised. Marquardt (2015) suggests that transitions management can offer a way to understand how local development aid can be scaled up. Brundiers & Eakin (2018) use a sustainability transitions framing to investigate windows of opportunity for sustainability in post-disaster settings.

These studies have variously demonstrated the value of using theory from sustainability transitions to understand pressing societal problems the Global South. At the same time, they have made clear some key differences between the North and South that need to be accounted for (Roxas, 2016). Notably, governance and institutions are more contested in the South and so regimes are typically less stable (Berkhout et al., 2009). Although unstable regimes can reduce lock-in (Grin et al., 2010), it has also been found that instability at the regime level can present obstacles for niche development (Berkhout et al., 2009; U. E. Hansen et al., 2018). For example, Verbong et al. (2010) discovered that the weak configuration of the established regime meant it was difficult to identify pathways for change and that niche experiments did not establish sufficient buy-in from regime-level actors. On the other hand, research suggests that less path dependency will reduce the time frame for transitions in the South (Wieczorek, 2018). In this case the landscape and the regime levels may become more blurred.

Reflecting on the limitations of applying sustainability transitions in the Global South, many authors have chosen to complement mainstream approaches with additional insights from other fields. For example, Onsongo & Schot (2017) recognise that theory on sustainability transitions is missing an important social dimension. To address this they integrate literature on inclusive innovation and sustainability transitions, by merging the MLP and Ladder of Inclusive Innovation framework. In addition, van Welie & Romijn (2018) adapt transitions management approaches to account for the need for empowerment and capacity building. Nygaard & Bolwig (2018) elaborate the MLP by using a global value chain framework. These studies provide examples of how additional theory can be integrated with sustainability transitions to address its particular limitations. The next section explores how a sustainability transitions framing can help to deepen our understanding of the main findings in this thesis. At the same time, it reflects on how DfSS can help to address concerns that the social dimension does not receive adequate attention in sustainability transitions (Onsongo & Schot, 2017; Tigabu et al., 2015).

7.3.2 Situating the findings using the Multi-Level Perspective

> *"Major changes are in reality prepared and made possible by the multiplication, interaction, and consolidation over time of small-scale radical changes… this happens both when particularly active people invent and put into practice an initiative that is (locally) completely new and when the success of the initiative leads it to stabilise and institutionalise, thus become (locally) normal: a kind of normality that remains transformative because it counteracts the orientation of the large scale dominant system."* (Manzini, 2019 p. 83)

Ezio Manzini is well-known for his scholarship on social design and sustainability. In his latest book it is clear that his thinking about the potential for transformative design has been influenced by literature on sustainability transitions. In the above quote he essentially describes how niches can offer radical alternatives to the status quo, and can become empowered to bring about changes in the dominant socio-technical regime. Underlying this position is the belief that niches are necessarily counteracting the regime, and that a power struggle is evolving between these two levels. However, as it was explained earlier that the linkages between different levels are reciprocal and dynamic (Loorbach et al., 2017). What this means is that the regime can also have an influencing effect on the niche, to the extent that it controls or constrains it.

A. Smith & Raven (2012) investigate two ways in which niches become empowered, that is they become competitive with the existing regime or they influence the regime to become more favourable. The first type of empowerment is 'fit and conform'. This approach does not change the selection environment but aims to put forward a competitive proposition within the existing conventional regime configuration. An organisation switching to 3D printing because it is cheaper would be an example of this fit and conform strategy. The second approach is 'stretch and transform'. This approach radically redefines the mainstream selection environment to make it more favourable to the niche. For example, if regime-level actors started to recognise the superiority of local manufacture over imported products, localised 3D printing might become more attractive in the aid sector. These two different strategies are important to bear in mind because they show that despite common assumptions, niches will not necessarily counter the dominant regime. In fact, as Avelino (2011) explains niches can be either moderate or radical. Moderate niches exert reinforcing power to reproduce the existing regime and trends. They have a synergetic relation with the regime and in this case are closer to 'fit and conform' strategies. Radical niches on the other hand demonstrate transformative power; they challenge the existing regime and have an antagonistic relationship with the incumbent regimes. These niches effectively 'stretch and transform' the prevailing regime into a new configuration.

Figure 7.3 illustrates how moderate and radical niches can either reinforce the incumbent or an emerging regime. In this representation, DF4D projects are presented as niche-experiments, that take place within niches. Taking a look back at Chapter 3, I remind the reader that despite rhetoric that DF4D is enabling a new way (ending the cycle of dependency in the aid sector), it was discovered that in reality many projects were replicating the old way. In other words, they were still 'outsider interventions' that were reliant on imported physical and human capital. In Figure

7.3, these projects exist within moderate niches. They use new technologies (digital fabrication) to create technological innovations that reinforce the dominant socio-technical regime in the aid sector, which is premised on the diffusion of technology from the North to the South. In contrast, it is put forward that DF4D projects which address DfSS are radical niche-experiments. These projects directly counter the mainstream narrative in the aid sector by seeking radical, systems-focused solutions; they place emphasis on endogenous design, active actors, capability-driven and open-ended solutions. Whilst the incumbent regime is predicated on the diffusion of technology, the emerging regime is centred on the local design and production of aid items. This emerging regime reinforces landscape trends such as the proliferation of digital fabrication tools in the Global South, which further helps to destabilise the incumbent regime. In this model, it is suggested that DfSS has an important role to play in cultivating radical niches, and thus DfSS contributes to the transformation of the socio-technical regime towards a more socially sustainable configuration. Table 7.4 tentatively suggests a taxonomy of the incumbent and emerging regime.

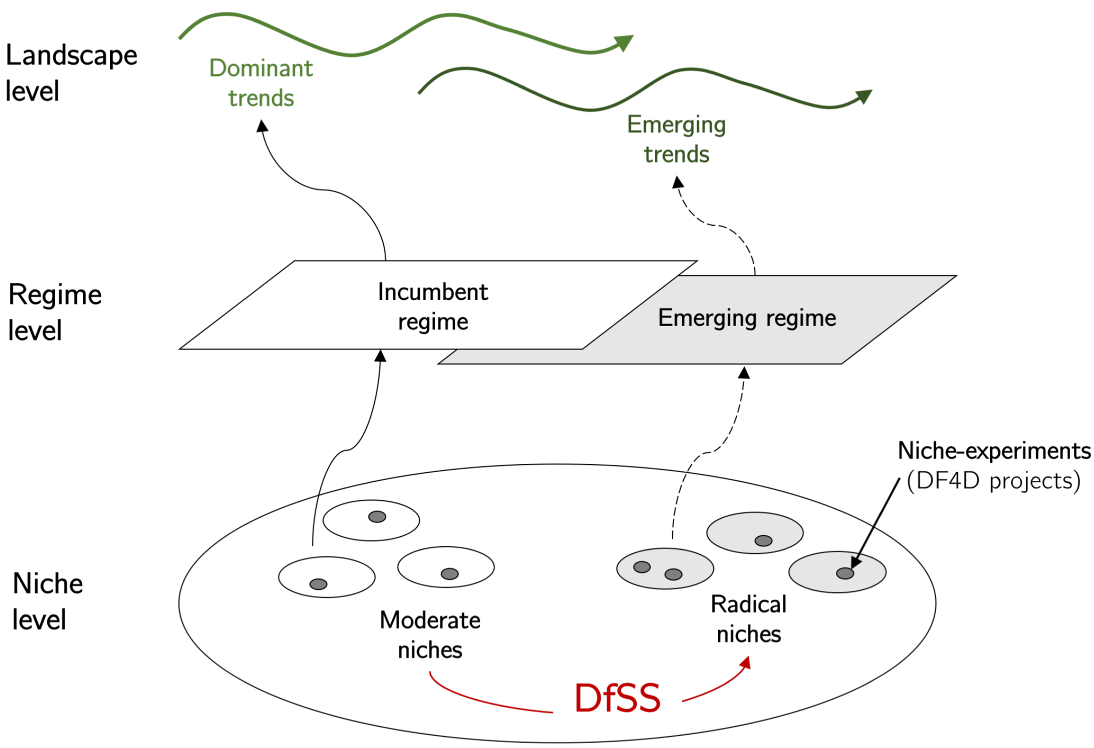


Figure 7.3 – Illustration of how DfSS can support radical niches that reinforce emerging regimes and trends

Table 7.4 – Taxonomy of the incumbent and emerging regime

	Incumbent regime *Diffusion of technology from North to South*	**Emerging regime** *Local production in the South*
Technological	Not enabled by digital fabrication Centralised	Enabled by digital fabrication Distributed
Socio-cultural	Insular Dependency	Networked Empowerment
Policy/user and market	Exogenous development Passive actors Products Quick fixes	Endogenous development Active actors Capabilities Open-ended solutions

7.3.2.1 How does DfSS help to support the viability of the niches?

Theory on sustainability transitions suggests that the development of niches is an important step in the transformation of the socio-technical regime. These niches offer alternatives to the dominant logic, and can influence the regime-level during windows of opportunity (Geels, 2014). For clarification, niches are protected spaces which allow for the development of niche-experiments i.e. DF4D projects. In the previous section it was put forward that DfSS can help to maximise the transformative and radical potential of niches. This section expands on this proposition to consider how the main outcomes of this study (the DfSS for DF4D framework and Designet toolkit) can support the viability of niches/niche-experiments. Previously it was explained that the viability of niches depends on: (i) the shaping and alignment of expectations; (ii) the formation of actor networks; (iii) learning processes. This section will identify how the main practical outcomes of this thesis contribute to these three areas of niche development. Table 7.5 offers a summary of this discussion.

In terms of shaping alignments and expectations, the DfSS framework provides a valuable set of guidelines for practitioners and establishes a clear vision for what social sustainability looks like in DF4D projects. Embedded in the framework is the belief that user-focused, incremental solutions are insufficient and that a sole focus on product attributes means that projects will fail to maximise social sustainability. More precisely, the framework sets out that product, process and paradigm factors must be integrated into DfSS to enable new ways of doing and thinking about things. The Designet toolkit on the other hand, allows actors in DF4D projects to unpack DfSS for themselves. It provides a means to uncover (mis)allignments between different actors and thus creates an important space for dialogue and negotiation. In doing so, it also contributes to the formation of much-needed actor networks. The toolkit allows actors to construct their own networks and to recognise problematic areas which undermine their efforts. It helps practitioners to identify possible new configurations for their networks and to better understand how resources can be allocated to support DfSS. In this way, the toolkit helps to nurture individual niche-experiments and to increase the viability of the niche.

Table 7.5 – How the main outcomes of this thesis contribute to the viability of niche/niche-experiments in DF4D

	Shaping alignments and expectations	**Formation of actor networks**	**Learning processes**
DfSS for DF4D framework (Chapter 5)	Establishes a normative guide that sets out criteria for social sustainability in DF4D projects. Establishes the importance of systems-focused, radical solutions in a simple heuristic.		A planning and evaluation framework that can help to identify how DF4D projects address social sustainability. Provides quick feedback on projects that is easy to share and can guide future decision making.
Designet toolkit (Chapter 6)	Facilitates sensemaking among different actors. Actors can negotiate shared visions for DF4D projects. Misalignments are uncovered and used as a means for interrogating the different relationships in networks.	Enables actors to visually represent their own networks to build up an understanding of them. Helps actors to dismantle and rearrange networks to address barriers to social sustainability.	Actors can learn from each other and identify problematic areas of their DF4D projects which require further attention. Networks are owned by the actors and can contribute to an ongoing learning process.

Finally, both the DfSS framework and the Designet toolkit provide important aids for facilitating learning. The framework can be used as both a planning and evaluation framework in DF4D projects. It provides a mechanism for quick feedback that enables easy comparison between different projects, thus supporting learning within niches. The toolkit also supports ongoing learning, as it provides a platform for actors in DF4D projects to take collective ownership of their networks and to manage them during the projects. It offers an important space for de-risked learning, and encourages actors to explore problematic areas of their networks before their effects are even realised. It also alerts niche-actors to the effects of resource allocation within the niches. In summary, the framework and toolkit provide a complementary approach, that together address the three main support mechanisms for niche development. From this perspective, the main practical outcomes of this thesis (the DfSS for DF4D framework and Designet toolkit) can contribute to a wider transition to social sustainability in the aid sector.

7.3.2.2 Comparing the niches in the case studies

The main focus of this thesis has been at the DF4D project-level. In the MLP model, these projects are referred to as niche-experiments. However the niches, in other words the wider contexts in which the projects take place, are different for each of the cases in the main study. Each project takes place in a different geographical context and is developed by a different type of institution. Whilst it has been beyond the scope of the main study to explore these differences in detail, this section speculates about these contextual differences more broadly.

As a reminder, CS1 is developed by Field Ready, an NGO in Nepal; CS2 is developed by BETiC at IIT-B, a research institution in India; and, CS3 is developed by FabLab/MakerSpace Nairobi, a public makerspace in Kenya. Whilst this study recognises that there may well be significant geographical differences between these cases, it is notable that the Human Development Index shows that they all take place in Medium Human Development countries, which are ranked globally at =147, 129 and =147 respectively (UNDP, 2019). For this reason, attention is mainly turned to the institutional differences between these niches.

Geels (2004) suggests that to avoid the black box of institutions, the concept of rules can provide a useful framework. Regulative rules are explicit and formal rules that constrain behaviours, such as laws, protocols, and incentive structures. Normative rules reflect the accepted ways of doing things and include values, norms, expectations and codes of conduct. Cognitive rules explain the nature of reality and the meanings associated to things. They include priorities, beliefs, problem agendas, knowledge and models of reality. To build up a picture of the regulative, normative and cognitive rules for the institutions in the main case studies, it was necessary to gather some additional information. As was pointed out earlier, the main case studies focused on the DF4D project-level and did not consider the institutional context in depth. To gather additional data, it was decided to retrieve information from the organisations' websites using online content analysis[17]. For each institution, the 'about us' page was used to build up an understanding of the

[17] The following websites were visited for each of the case studies (January 2020). CS1: https://www.fieldready.org/about-us; CS2: https://www.BETiC.org/; CS3: http://makerspace.co.ke/about-us/

institutional rules. If this did not provide sufficient information, additional webpages were retrieved and reviewed. Clearly this approach is limited in so far as it only reveals how the organisations perceive themselves (or want to be perceived) at a particular point in time, yet it provides a useful starting point for understanding these institutions at large. In recent years, online content analysis has been used in a number of studies in the social sciences, education and psychology (De Wever et al., 2006; Gerstenfeld et al., 2003; Hara et al., 2000).

Table 7.6 summarises the regulative, normative and cognitive rules of the institutions in the main case studies. To begin with, it is worth acknowledging the different regulative rules that govern these institutions. Field Ready (CS1) is an NGO and therefore must follow the humanitarian principles of the incumbent regime. As an institution they are incentivised to develop innovative projects which demonstrate (short-term) impact to donors. Their funding is provided by government donors and international NGOs that constitute actors in the incumbent regime. One could speculate that this lends Field Ready's work to partially mirror the incumbent regime, which limits social sustainability. BETiC at IIT-B (CS2) on the other hand are a research institution, and so their funding is provided from actors outside of the aid sector. In this sense, the niche offers greater protection from the pressures of the incumbent regime. Similarly, FabLab/MakerSpace Nairobi (CS3) operate as a public makerspace and their day-to-day funding is provided by the University of Nairobi. Whilst their status as a public institution means they must follow government regulation, they are afforded additional protection from the incumbent regime of the aid sector which is seen as a positive for social sustainability.

The normative rules embedded in the institutions also seem to vary slightly among the cases. Field Ready (CS1) explain that their approach aims to bring manufacturing to challenging places. In other words their vision is grounded in the belief that technology will provide a solution. Their proposition is also positioned in competition with the incumbent regime, as they identify that their aim is to transform international aid so it is "faster, cheaper and better". In many ways, this seems closer to the 'fit and conform' strategy as opposed to the 'stretch and transform' approach which was discussed earlier. Put another way, Field Ready aims to compete with, rather than transform the existing regime. A look at the main findings seems to tie in with this. Specifically, Chapter 5 found that the focus on product attributes neglected more radical (and transformative) solutions. Chapter 6 also raised the concern that the digital fabrication tool was more influential than the end user in the network, pointing to a technology dominant approach. In contrast, BETiC's (CS2) vision is very much centred on the provision of expertise. The organisation positions themselves as key enablers for the endogenous development of medical devices. MakerSpace Nairobi (CS3) take this further by presenting themselves as the providers of enabling infrastructure. This also seems to be reflected in the findings in Chapter 6 that the design team in CS2 are responsible for the application of knowledge. In CS3 there is greater reciprocity of knowledge and information exchange between the end users and the designers, cultivating an enabling ecosystem.

Finally there are subtle differences in the cognitive rules which govern the institutions. Field Ready (CS1) identify that making products locally is a key priority. BETiC (CS2) elaborate on this to state that *developing* products locally is a priority. In contrast, MakerSpace Nairobi (CS3) outline the belief that local capabilities are tied to local empowerment and “freedom”. It is notable that these differences can also be found in the main studies. Chapter 5 shows that whilst CS1 certainly addresses the need for local manufacture and control, is neglects broader advancement beyond the Field Ready team. In contrast, advancement is an underlying motivation for CS2 and CS3, which contributes to social sustainability. Despite the differences between these cognitive framings, it is worth noting that these institutions all share an important emphasis on the ‘local’ which is notably absent in the dominant regime in the aid sector. That is to say that although these niches are unalike, they are consistent in their antagonistic relationship with the diffusion of technology which prevails in the dominant regime.

Clearly, this section has only scratched the surface on some of the differences between the niches and how this relates to their outcomes. Certainly additional work is needed to investigate the cases’ institutional rules in more depth, however, this discussion suggests that there is a relationship between institutional governance and the social sustainability of niches. Designing a transition to social sustainability therefore necessitates alignment between DfSS and niche governance. It is hoped that this discussion has offered some additional insight that enriches the findings and point towards new avenues for exploration.

Table 7.6 – Institutional rules which govern the niches in the main case studies

	Formal rules (the rules of the game) *e.g. laws, protocols, standards, incentive structures*	**Normative rules (how we do things)** *e.g. values, expectations, codes of conduct*	**Cognitive rules (orthodoxies)** *e.g. priorities, beliefs, knowledge, models of reality*
CS1: Field Ready (NGO)	– Follows principles of the incumbent (aid sector) regime: *"We subscribe to widely accepted humanitarian principles and endeavour to be a reliable and impactful partner everywhere we work"* – Funded by the actors in the incumbent regime	– Technology can solve problems: "*We bring manufacturing to challenging places, train others and create innovative solutions by engaging people in new ways."* – Compete with existing regime: *"Our vision is to meet humanitarian and reconstruction needs in ways that transform international aid so it is faster, cheaper and better than current alternatives."*	– Make products locally: *"We believe that by making useful things locally, we can make the world a better place and that people should have essential items where and when they need them"*
CS2: BETiC, IIT-B (research institution)	– Rewarded by (academic) impact: *"Several medical devices… are already in clinical studies and a few have reached the market through start-up companies or industry partners. The products have been showcased in different exhibitions and won prestigious awards."* – Funded by the actors outside of the incumbent (aid sector) regime	– Provide expertise: *"The core vision is to create global success stories of indigenous medical devices by providing the necessary guidance and support to med-tech innovators."*	– Develop products locally: *"Indigenous development of novel, suitable, reliable and affordable devices leads to social impact as well as high-value jobs."*
CS3: MakerSpace Nairobi (makerspace)	– Funded by the actors outside of the incumbent (aid sector) regime – Follow government regulation as a public institution.	– Provide enabling infrastructure: *"An environment designed to boost creativity and problem solving is the power source that will enable them to move beyond being individual 'Do-it-yourselfer' to the fun 'Do-it-with-others' a model that will help accelerate the transformation of African manufacturing."*	– Develop local capabilities: *"When given a chance, African dreamers, innovators, tinkerers, artists and makers can be empowered and supported to take a glimpse of the future and get inspired to find their freedom on products they wish to utilise through experimentation and exploration making and to remake Africa by their own hands one digital tool at a time."*

7.3.2.3 Destabilising the incumbent aid sector regime

The central aim of this thesis has been to understand how design promotes social sustainability in DF4D. The main study therefore focused on DfSS at the DF4D project-level. However, it found that DfSS implies the need for action beyond the project-level which magnifies the transformative potential of DF4D. In response, this discussion has taken a step back to integrate the main findings with the MLP model from sustainability transitions literature. So far this discussion has suggested that DfSS can contribute to the development of niches, and it has reflected on how the institutional governance of niches influences the social sustainability of niche-experiments. The main practical outcomes of this thesis (the DfSS in DF4D framework and the Designet toolkit) have been presented as techniques to maximise the transformative potential of niches. However, it has also been pointed out that niches are an insufficient precondition of regime shift (Berkhout et al., 2009). In other words, the framework and toolkit developed in this thesis are not enough to secure social sustainability at the regime-level. Sufficient pressure must also be applied from the broader landscape, to the effect that *"the regime experiences major internal problems, collapses, erodes and fragments. Regime actors lose faith in the current system and defect."* (A. Smith, 2007). In light of this, this section considers some of the landscape-level and regime-level factors that influence the (de)stabilisation of the incumbent aid sector regime.

The transformation of the socio-technical regime in the aid sector is recognised as a necessary response to global trends and local pressures (Clarke & Ramalingam, 2008). Yet there are many factors which contribute to the path dependency and lock-in of the prevailing regime (Geels, 2014). As a reminder, the incumbent regime is predicated on the diffusion of technology from the North to the South and constitutes the traditional way of doing things in the aid sector. The emerging regime is countervailing to this agenda, and proposes a new socio-technical system that favours local solutions in the South for the South. This transition is set against a landscape of deep cultural, economic and political trends. In this landscape, there are a set of emerging trends which may well contribute to the destabilisation of the existing regime. An obvious trend here is the proliferation of digital fabrication tools in the Global South (Sniderman et al., 2016). A growing availability and understanding of these technologies opens up new possibilities for how humanitarian and development aid is managed. A second relevant trend is the rising number of protracted and complex problems (OCHA, 2015). These crises are placing increasing pressure on the incumbent regime and exposing its cracks. A third pertinent trend is the shift in the political dynamics of the actors in the aid sector (Maietta et al., 2017). Non-formal actors that have been operating on the periphery of the aid sector such as private companies, local NGOs, research institutions and new donors are becoming more involved in the aid ecosystem. This is challenging the dominance of formal aid sector actors and may well contribute to the destabilisation of the existing regime.

Of course these landscape trends are not exhaustive, however they point out some possible windows of opportunity for niches to challenge the prevailing way of doing things. At the same time, resistance from the incumbent regime creates inertia (Geels, 2014). Clarke & Ramalingam (2008) identify that actors in the aid sector will strongly resist changes that threaten their models of reality. They conduct a detailed review of the key barriers to change in the aid sector, and their analysis is summarised in the following points. First, they find that uncertainty about change and lack of a shared vision is an obstacle. They point out that it is often difficult to absolutely evaluate the impact of interventions, to say that this did or did not work, and so it is difficult to create substantial motivation for change. Added to that the prevalence of short-term thinking reduces the space for reflection and learning, which are both prerequisites to change. Second, the authors highlight the highly fragmented and competitive ecosystem in the aid sector. Different actors have specific mandates that prevent them from taking more systemic action. Third, employee turnover is typically high and contributes to regime instability. Whilst this can create a window of opportunity it also undermines long-term transitions. Fourth, there are weak links between the recipient and the donor. There is often little recourse for failure as no feedback is established between the beneficiary and the donor. Finally, decision making is often top-down and takes place far away from the location of need, so decision-makers are not aware of the need for change.

Whilst these factors create substantial barriers to the transformation of the existing regime, Clarke & Ramalingam (2008) also suggest a possible way forward. They identify several practices that reframe the main obstacles to change in the aid sector. First, they place emphasis on galvanising motivation for change, by creating internal and external support. They highlight the importance of capitalising on regime instability, by using this as an opportunity to drive further change. Second, the authors recognise the importance of gathering the resources needed for change. This includes building new structures, removing redundant policies and creating new ones. Third, they highlight the importance of making change locally appropriate and flexible. On top of this, any transformation should be related to the underlying organisational values. In a similar vein, Elbers & Schulpen (2015) find that successful transitions in the aid sector maintain consistency with the organisation's core values.

Figure 7.4 shows an updated view of the MLP model that reflects the discussion in this section. It identifies speculative transition pathways for DF4D to challenge the incumbent aid sector regime. The figure highlights that initially the socio-technical landscape motivates the development of niche-experiments (DF4D projects), however these are constrained by the existing regime. As a result, these niche-experiments tend to mimic the established regime. Evidence of this was found in Chapter 3, where DF4D projects replicated traditional aid agency models, even if they presented themselves as countervailing to these. The figure highlights the important role that DfSS can play in the development of radical niches which challenge the prevailing regime. It shows that increasing pressure from these niches and the exogenous landscape eventually leads to the destabilisation of the prevailing regime. This creates sufficient motivation for change at the regime-level. As a result, adjustments occur and a new (more socially sustainable) regime emerges.

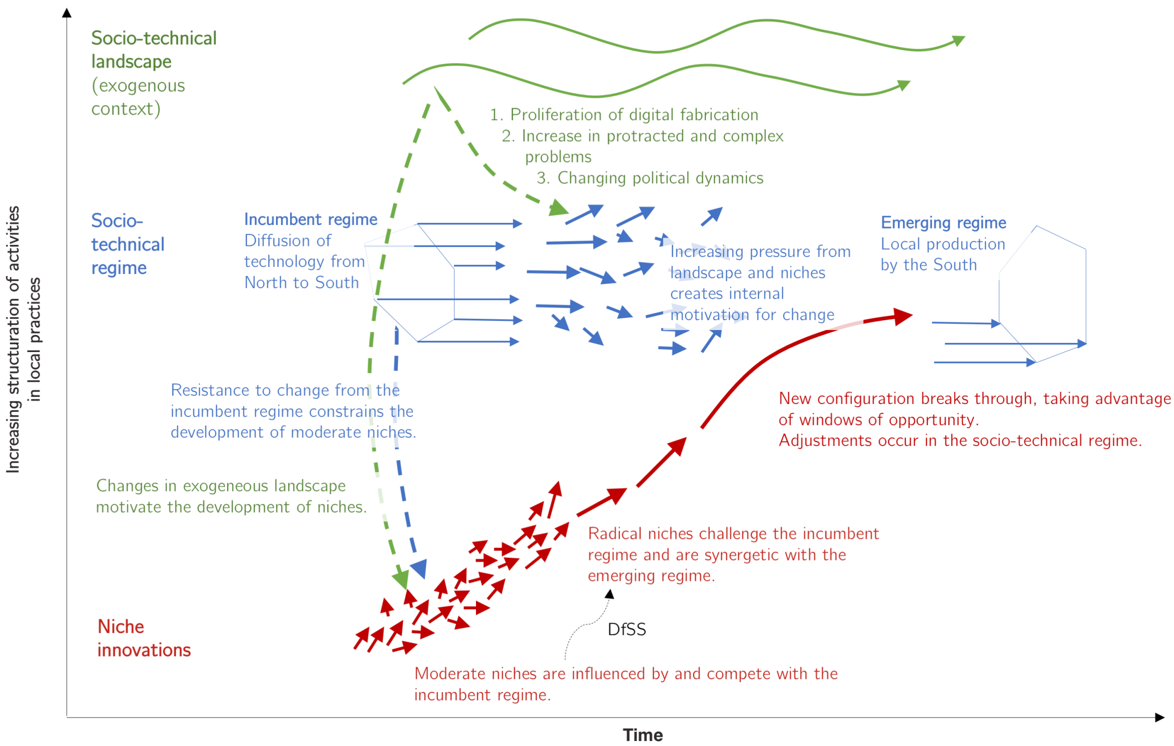


Figure 7.4 – MLP model showing speculative transition pathways for DF4D to challenge the incumbent aid sector regime

At this point it is worth repeating that this discussion is couched in speculation. Figure 7.4 is certainly not a prediction of what will happen, however it suggests one possible way that a transformation in the aid sector might unfold. It is presented here to help position the findings of this thesis and to make clear that social sustainability necessitates the alignment of multiple analytical levels. Whilst the practitioners in the case studies regard their work as a substantially novel socio-technical configuration (a niche according to Berkhout et al. (2009)), they are not necessarily aware of their position in the MLP model. This discussion suggests that the practical outcomes of this thesis (the DfSS in DF4D framework and the Designet toolkit) are focused at the niche-level. This part of the chapter has looked beyond this level to consider what else is needed to realise the transformative potential of DF4D. It has reflected on the potential for DfSS in DF4D to support widespread transformations to social sustainability in the aid sector. Ultimately DfSS in DF4D calls for a different way of doing and thinking about things, which demands a broader shift in cultural, political and technological values that must be aligned at the niche, regime and landscape levels. The exact linkages between these levels remains unclear, however it is hoped that this discussion offers a first step towards their exposition.

I choose to end this part of the chapter with a quote from the eminent post-development theorist, Arturo Escobar. It serves to remind us of the closely intertwined nature of our theoretical models and our understanding of the world.

> *"There is always a tight connection between social reality, the theoretical framework we use to interpret it, and the sense of politics and hope that emerges from such an understanding. This connection is often overlooked. It can be said without much exaggeration that our hopes and politics are largely the result of a given framework. It is particularly important that we reflect on this fact in times of profound transformations, such as today."* (Escobar, 2012a)

In this discussion, the MLP model has deepened our understanding of DfSS in DF4D in several ways. First, it helped to position DF4D projects as important niche-experiments which challenge the incumbent regime. It used the MLP to reflect on how individual DF4D projects might contribute to a broader transition to social sustainability. Second, this discussion has proposed that DfSS can help to maximise the transformative potential of niches. It has also questioned the influence of the niche's institutional governance on social sustainability. Third, the MLP has provided a means to consider how the incumbent regime might become destabilised, such that the transformative potential of DF4D becomes more evident. Finally, the main findings in this thesis have also contributed to the MLP by suggesting how a social dimension could be added to the model. DfSS has opened up thinking about sustainability transitions in a way that is concrete and manageable for organisations. Overall, this discussion has enriched the findings of this thesis by speculating about their implications in the broader context. It has provided some valuable additional insights that offer a basis for further study. The following part of the chapter will draw the discussion to a close by reflecting on what this means for the role of design.

7.4 The changing role of design

According to Tonkinwise (2015) the potentially transformative role of design has not been fully recognised, even by designers themselves. This thesis contributes to this dialogue by presenting design as a catalyst for social sustainability in DF4D. Importantly, the study has shown that to realise the transformative potential of design, design practice itself must evolve. The findings place emphasis on a practice that prioritises endogenous, participatory, capability-driven, open-ended and scalable solutions. Beyond that, the responsibility of design has been expanded, from being primarily concerned with the creation of products (as is noted in many Design for Sustainability approaches) to focusing on the design of projects.

In 'Politics of the Everyday', Manzini (2019) describes a project as *"a sequence of conversations and actions on the world, the aim of which is to bring it closer to the way we would like it to be."* This definition is remarkedly similar to Simon's (1988) version of design as "*courses of action aimed at changing existing situations into preferred ones*". Manzini continues his description of a project to explain that:

> *"Doing [a project] entails designing: making a critical evaluation of the state of things, imaging how we would like them to be and having the necessary relational system and tools at hand to transform them - and all this in terms of both their practical functioning (problem solving) and their meaning (sense making). From these definitions of project and designing derives a defining of "design" as "project making" in the sense that anyone doing what I have just said can be seen as a project maker."* (Manzini, 2019 p. 37)

In conceptualising the designer as a project maker, Manzini draws attention to the dual nature of design: problem-solving and sensemaking. The analytical and critical systems approaches in this thesis respond to both these dimensions. As was discussed earlier, the DfSS in DF4D framework takes a problem-solving approach, helping designers to solve complex challenges. In contrast, the

Designet toolkit prioritises sensemaking, allowing actors to build up a shared understanding of their networks. In this approach, design plays an important role in the construction of actor networks, further evidencing its impact beyond the creation of artefacts: *"what design brings into being not only influences the nature of the world we human beings inhabit, but equally affects what we become as actors within that work"* (Fry, 2011, p. 38). It follows that DfSS is much less about achieving a final outcome than supporting an ongoing process of change. DfSS helps to cultivate the environments in which projects may flourish, as well as influencing the wider eco-system in which these projects are situated. It can be said then that design is not just about project making, but that it requires multi-project and multi-level thinking.

To return to earlier suppositions about the political nature of design (Fry, 2011; Manzini, 2019), this thesis reaffirms the central role that design must play in bringing about social sustainability. Design is positioned as a lever for change, that can help to promote alternatives to current un-sustainability. This in turn demands what Tony Fry describes as the development of redirective practice. Designers must interrogate their own values and knowledge in order to identify where they have been 'educated in error' (Fry, 2008, p. 174). In order words, designers (and indeed all actors in DF4D projects) must challenge the underlying beliefs which constrain their current ways of thinking and doing. In the aid sector, this requires a particularly deep reflection on postcolonial discourse (Escobar, 2012a).

Another important point that has not been discussed yet is the need for designers to re-evaluate their role in relation to technology. Despite the fact that designers have become accustomed to the view that all problems can be solved with technology (Ehrenfeld, 2008, p. 17), the findings in this study point towards the reality that technological fixes are not enough. In Escobar's (2012) critical account of the aid sector, he reflects on the broken promises of science and technology:

> *"Technology it was believed would not only amplify material progress, it would also confer upon it a sense of direction and significance. In the vast literature on the sociology of modernisation technology was theorised as a sort of moral force that would operate by creating an ethics of innovation, yield and result. Technology thus contributed to the planetary extension of modernist ideals. The concept of the transfer of technology in time would become an important component of development projects. It was never realised that such a transfer would depend not merely on technical elements but on social and cultural*

> *factors as well. Technology was seen as neutral and inevitably beneficial, not as an instrument for the creation of cultural and social orders."* (Escobar, 2012a, p. 36)

As well as pointing out the problematic diffusion of technology model that predominates in the aid sector, Escobar notes the lack of attention given to the social and cultural dimensions of technology projects. This thesis goes some way to addressing this imbalance, by proposing a contextual view of DfSS that accounts for social/cultural factors. It is notable that among the sixteen factors identified in the DfSS framework in Chapter 5, none (explicitly) refer to digital fabrication. So much to say, that the principles of DfSS in DF4D are not rooted in a technological view. The belief that technology is not neutral, but should be socially and culturally embedded is also reflected in the critical systems approach taken in Chapter 6. Using ANT as a methodological framing served to dismantle the hierarchy between social and technical systems, whilst also highlighting their inseparable nature. It is evident then that a one-sided, technological view of DF4D is insufficient, and that it is certainly not compatible with the view of DfSS presented in this thesis.

Reflecting on the initial concerns about DF4D projects, it is clear that if they are to avoid the same fate as other technology projects in the aid sector, they simply must stop behaving like traditional technology projects. In this thesis, it is suggested that DfSS can support a transition towards new ways of thinking and acting. Specifically it has been speculated that DfSS in DF4D might help to dismantle the practice of the transfer of technology from the North to South, in favour of locally developed solutions. To this extent, the findings point towards literature on decolonising design and development by authors such as Dori Tunstall, Boaventura de Sousa Santos and Arturo Escobar. 'Notes on the Ontology of Design' (Escobar, 2012b) and 'Designs for the Pluriverse' (Escobar, 2018) underline the importance of alternative knowledge paradigms in the development of sustainable solutions. In response, this research draws attention to the need for more decolonial design perspectives to promote social sustainability in DF4D. At the same time, the researcher recognises the inherent limitations of this work, originating from a Northern perspective. Caution is therefore reserved against the "*too-easy adopting of decolonising discourse*" (Tuck & Yang, 2012, p. 3) such that it loses its meaning. To conclude, the researcher recognises the reality that we live in *"a world where many worlds fit"* (Escobar, 2018, p. xvi) and invites further perspectives that can amount to a plurality of world views.

7.4.1 Addendum on the broader sustainability discourse

Before ending this discussion, it is worth adding a final note on how DfSS relates to the broader sustainability discourse. At the start of this thesis, it was put forward that social sustainability was a key gap in DF4D projects which needed to be addressed. It was also argued that integrated models of sustainability had failed to adequately consider social factors (McKenzie, 2004; Missimer et al., 2017a). It was supposed that these social factors, were key to the success of DF4D projects. For these reasons, this study has explicitly focused on the social dimension of sustainability.

Whilst recognising the call for holistic approaches to sustainability (Zink, 2014) this research also remains mindful of critical views of mainstream sustainability. The most vocal critiques are found in literature on degrowth, which considers that the continual economic growth that underlies economic sustainability, is fundamentally in tension with the social and environmental protection of society (Kallis, 2018). Notably, Fry (2011, p. 23) calls on designers to 'face finitude' and abandon the idea of continual quantitative growth. In line with this, he moves away from sustainability to call for 'Sustainment', the overcoming of the unsustainable. Other authors have recently called for further exploration of the linkages between design for sustainability and degrowth perspectives (Gaziulusoy & Erdoğan Öztekin, 2019; Gaziulusoy & Houtbeckers, 2018).

So what, does this mean for this thesis' account of DfSS? Despite reservations about mainstream models of sustainability, it is worth noting this work is not necessarily in conflict with traditional three-dimensional models (Scott Cato, 2012). In fact, Chapter 5 presented a way in which practitioners might adopt the DfSS framework as a first step to address broader sustainability concerns. It was suggested that practitioners could begin by examining the social dimension of sustainability, as also suggested by Boyer et al. (2016), and then consider the implications on economic and environmental dimensions. This feedback could be used to continuously adjust decision making in the design process, until an optimum scenario is reached for sustainability as a whole. Although the findings in this thesis seem to be compatible with the three-pillar approach, the researcher remains cautious about the linkages especially in light of concerns around the unsustainable reality of economic sustainability. One might also consider that whilst the environmental impact of DF4D does deserve attention, its footprint is likely to be just a fraction of global industrial systems. That is not to overlook the potential significance of environmental sustainability in DF4D and the need for separate studies in this area to complement a significant body of research on environmental sustainability and digital fabrication (Agustí-Juan & Habert, 2017; D. Chen et al., 2015; Fleischmann et al., 2016; Kohtala & Hyysalo, 2015).

7.5 Summary of the chapter

This chapter ends the discussion of this thesis which has been structured in three main parts. The first part of the chapter started by comparing the analytical and critical systems approaches that were used in the main study to investigate DfSS in DF4D. It highlighted the main differences between the outcomes, as well as pointing out their complementary insights. Specifically, this discussion set out the need for more endogenous, participatory, capability-driven, open-ended and scalable solutions.

The second part of the chapter zoomed out to position the findings in relation to literature on sustainability transitions. The MLP model was identified as a way of reflecting on how disparate DF4D projects could more broadly influence a transition to social sustainability in the aid sector. DF4D projects were framed as niche-experiments that occur within niches. It was suggested that DfSS can help to maximise the transformative potential of these niches such that they challenge the incumbent aid sector regime, which is predicated on the diffusion of technology from the North to the South. The differences between the niches in the case studies were briefly discussed before attention was turned to how the incumbent aid sector regime might become further destabilised, such that a potentially more socially sustainable regime might emerge.

The final part of the chapter returned to focus on the role of design in promoting social sustainability. It firmly underlined the importance of design in manifesting change. It also pointed out the need to rethink the relationship between technology and design, acknowledging the importance of postcolonial/decolonial perspectives on DfSS in DF4D. Finally, the discussion commented on how DfSS relates to broader discourse on sustainability.

In total, this discussion has contributed to the development of DfSS, which at the start of this thesis was introduced as an ill-defined and contested concept. It has clarified the importance of DfSS in DF4D, as well as its compatibility with literature on sustainability transitions. It has also indicated some furthers areas for research, which will be addressed formally in the following chapter. The next chapter will conclude the thesis by articulating its main contributions, highlighting the limitations of this work, as well as identifying further areas for research.

Chapter 8 Conclusions

8.1 Introduction

The previous chapter presented a discussion of the main findings. It drew together the two main outcomes of this thesis, which were independently based on analytical and critical systems approaches. The discussion paid attention to their different perspectives as well as highlighting their complementary insights. The previous chapter also built on theory from the field of sustainability transitions in order to help situate the findings in the broader context. This amounted to a greater understanding of how Design for Social Sustainability (DfSS) can maximise the transformative potential of Digital Fabrication for Development (DF4D). This chapter follows on from the discussion to conclude the thesis. Section 8.2 begins by summarising the findings. Section 8.3 identifies the theoretical, practical and methodological implications of this work. Section 8.4 formally articulates the contribution to knowledge. Section 8.5 identifies the main limitations of this thesis and Section 8.6 outlines possible areas for future research.

8.2 Main findings

This thesis set out to understand how design can promote social sustainability in DF4D. It has revealed that:

- DfSS in DF4D calls for the integration of product, process and paradigm factors. It puts forward that the integration of these three dimensions marks a shift towards more radical, systems-focused DfSS.
- Participation is an important dimension of DfSS in DF4D, which can be differentiated in terms of flows of knowledge, information, materials, money and intangible values.

Reciprocity has been highlighted as a key network metric that can reveal (in)equitable relationships.

- DfSS in DF4D necessitates several shifts in practice from products to capabilities; exogenous to endogenous solutions; passive to active actors; quick fixes to open-ended solutions; and, one-off projects to scalable interventions.
- DfSS can help to maximise the transformative potential of DF4D, in order to bring about a broader transition to social sustainability in the aid sector.
- It is possible to develop practical approaches for supporting DfSS in DF4D.
- Integrating analytical and critical systems perspectives can help with the study of complex phenomena such as DF4D. Ontological pluralism is a valuable tool for the design researcher.

Theoretical implications

This thesis has contributed to the conceptual development of DfSS in the DF4D context. At the start of the thesis social sustainability was introduced as an important but often overlooked concept. It was also discovered that although DfSS appeared in the literature, it was ill-defined and often used with little precision or clarity. Specifically, there were few attempts to define DfSS, and it was often used interchangeably with other related concepts such as 'socially responsible design' and 'design for social innovation'. It was put forward that this lack of understanding about DfSS was limiting the success of DF4D projects.

This thesis has synthesised a fragmented field of knowledge and has helped to build a contextually appropriate understanding of DfSS. Instead of focusing on a single definition, Chapter 5 developed a set of factors which reveal the constituent parts of DfSS. This work was developed through case studies and built on existing literature. It showed that previous accounts of DfSS were missing some key dimensions that are fundamental in DF4D. Specifically, it highlighted the frugal attitudes of DF4D practitioners who emphasised the importance of durability, adjustability and quality. It also helped to clarify the importance of local manufacture, control and repair. Whereas literature on DfSS emphasises the role of small and local initiatives, this study has revealed that DfSS in DF4D implies a need for more scalable impact. Notably, DfSS in DF4D necessitates more than just product-based thinking. Designers must equally address product, process and paradigm factors to consider the entire project. The findings establish a link between DfSS and theory on systems design and innovation, by suggesting that DfSS favours both systems-focused and radical solutions over user-focused and incremental ones.

Chapter 6 expanded our conceptual understanding of DfSS from another point of view. ANT served as a methodological guide to interrogate the networks of DF4D projects. Whilst it was previously understood that participatory design practices would advance DfSS, the main findings helped to clarify this by developing an ontology of the different types of interaction (and de facto participation) that take place in DF4D projects. It was put forward that participation can be differentiated with respects to knowledge, information, materials, money and intangible values. This study specifically highlighted that the reciprocal exchange of knowledge and information can provide a foundation for equitable relationships. In the absence of these exchanges, it was shown that participation can actually reinforce inequality and thus undermine ambitions for social sustainability. Although there have been some significant attempts to unpack participation in the past, previous work does not clearly specify the types of participation and their various impacts, much less explicate how the type of participation affects DfSS. This research thus expands on existing knowledge about how participation plays a role in DfSS.

Finally, the discussion in Chapter 7 established areas of overlap between the two main studies, resulting in further development of the DfSS concept. It highlighted that DfSS in DF4D necessitates several shifts in practice from: products to capabilities; exogeneous to endogenous development; passive to active actors; quick fixes to open-ended solutions; and, one-off projects to scalable interventions. Complementary theories from design, innovation and development studies were identified to enrich these findings. The chapter also established a link between DfSS and theory on sustainability transitions. This helped to shape a discussion on the potential of DfSS in DF4D beyond the project-level. Specifically, the Multi-Level Perspective model was used to position DF4D projects as niche-experiments. This framing helped to explain that DfSS in DF4D can play a role in the broader transformation to social sustainability in the aid sector. It also identified several promising areas for further research which will be addressed later in the chapter.

8.2.1 Practical implications

This thesis has contributed to the practical development of DfSS in DF4D. The DfSS in DF4D framework and Designet toolkit offer ways to respectively explore normative and interpretative versions of DfSS.

The DfSS in DF4D framework provides guidelines that can assist practitioners working on DF4D projects during planning and evaluation. The framework puts forward a firmly normative view of DfSS. In other words, it expresses a set of factors that signal how DfSS should be in DF4D. The advantage of this approach is that it offers clear guidance to practitioners and it allows for the easy comparison of different projects. The framework itself is simple to use and it includes open-ended questions to prompt evaluation.

The practical value of the framework was evidenced in the analysis of three case studies in Chapter 5. Sharing these evaluations with practitioners led to critical reflection and collective learning. The organisations involved in the case studies were interested in using the framework in their future projects, further confirming the potential value of this framework in real-world applications. In the previous chapter it was pointed out that the principles of DfSS embedded in the framework are rooted in a particular social and cultural view, as opposed to a technological one. It is therefore speculated that this framework could well be used to support other projects in the aid sector, not necessarily just projects using digital fabrication tools.

The Designet toolkit offers a complementary perspective to the framework, by guiding participants to explore their own versions of DfSS. It is intended to be used during ongoing DF4D projects. Unlike the framework, the toolkit does not mandate a particular vision for DfSS in DF4D, but rather facilitates the collective construction of DfSS among different stakeholders. Practically, it is believed that Designet offers two main benefits. First, the toolkit helps to collect data about the networks of DF4D projects. It specifically responds to calls for more emancipatory and designerly ways to capture this network data. In Chapter 6 it was shown that these representations can be transferred into a digital format for further analysis using software such as Kumu. These digital representations can reveal useful network patterns that help to develop a richer understanding of DfSS in DF4D. The second practical benefit of Designet is that the toolkit can provoke immediate insights and serve as an intervention in DF4D projects. Designet helps practitioners to build up a shared understanding of their networks and to collectively tackle inequitable relationships that are barriers to social sustainability. Through use, Designet creates a protected space to challenge conventional thinking and to imagine ways to rearrange the networks in DF4D projects. Importantly it prompts actors to explore and align their decision making with DfSS.

It is important to note that at this stage Designet is only an initial toolkit or more precisely a proposal for a tool. To develop Designet into a fully validated tool would require further iterative cycles of design and testing. Whilst Designet has been developed so far for the DF4D context, the flexibility of the toolkit means that it could also be adapted for other applications. Its interpretative position and flexible ontology means it is likely to be generalisable for other types of projects that seek to advance DfSS. In the previous chapter it was noted that within the aid sector, systems approaches are often regarded as inaccessible and impractical to implement. Designet may well offer a means to overcome the perceived difficulty of using a systems approach in a range of humanitarian and development projects. The need for designerly ways to map networks means the toolkit could have applications in other areas of sustainable design, including energy, mobility, healthcare and agriculture. Beyond that, it is also possible to imagine using a version of Designet to address complex societal problems in the Global North.

8.2.2 Methodological implications

This thesis weaves together an analytical and a critical systems approach to explore DfSS in DF4D from two different perspectives. In this thesis, it has been shown that both approaches can independently advance the conceptual and practical development of DfSS in DF4D and that taken together they provide a much richer perspective.

Although literature suggests that analytical and systems approaches are complementary, studies that use both perspectives can rarely be found. Whilst this research approach is very much in line with the pragmatic world view, it is noted that pragmatic studies tend towards epistemological pluralism (i.e. combining mixed methods research) as opposed to ontological pluralism (i.e. recognising different ways of being). To clarify this point, the analytical perspective tends to view the world as an objective, fixed reality, whereas the systems perspective views the world as a constructed entity. Thus, they are rooted in different ontological perspectives. In this thesis, it can be said that the analytical approach implies a critical realist ontology, whereas the critical systems approach implies a constructivist ontology. According to pragmatism, this ontological pluralism is acceptable and indeed desirable (Ghiara, 2020). Although ontological pluralism is being more widely recognised as an approach (Spencer, 2012), examples of its adoption in research are difficult to find. This thesis expands on earlier work by Aranda-Jan (2018) to combine Actor-Network Theory (systems) and 'factorisation' (analytical) approaches. This research adds to previous work by clarifying the ontological positions of these approaches, as well as specifically explaining how and why these approaches are complementary. As far at the author is aware, this is the first study that specifically combines an analytical and a critical systems approach.

To remind the reader, the analytical approach is based on a problem-solving logic which aims to break down complex phenomena into their constituent parts. In this thesis, an analytical approach supported the development of the DfSS in DF4D framework. The framework itself identifies multiple criteria and it strives for completeness in its presentation of DfSS. In contrast, the critical systems approach pays attention to the interaction between different elements, aiming to understand complex phenomena as a whole. This perspective guided the development of the Designet toolkit. The toolkit focuses in more detail on the specific themes of participation in DfSS. In summary, the analytical approach resulted in a broad but shallow conceptual focus, whereas the critical systems approach resulted in a narrow but deep conceptual focus. Integrating both these two perspectives therefore builds up a much more detailed account that balances the search for breath and depth.

Considering the successful application of these two approaches, it is suggested that other studies in the aid sector could benefit from combining them. The potential for a critical systems approach is particularly significant in this context, given its emphasis on emancipatory research. An analytical approach can also help to reduce the practical challenges of implementing a critical systems approach, by building up much-needed knowledge about the various parts of the system. Beyond applications in the South, it is believed that this pluralist approach could be useful in sustainability studies in the North. Globally, we are facing increasingly complex problems, for which existing solutions are no longer suitable. Pragmatic thinking is therefore urgently needed to search for new solutions by any means possible. Of course the researcher is well aware of the practical challenges of combining both analytical and systems approaches into academic work. Such work requires detailed analysis that is possible in the form of a thesis but perhaps more difficult in the length of a typical journal paper. In spite of these challenges, the researcher hopes that this thesis provides evidence of the significant advantages of using both approaches, and that this work encourages other academics to explore their complementary perspectives further.

8.3 Contributions to knowledge

So far the theoretical, practical and methodological implications of this thesis have been outlined. The main contributions to knowledge are succinctly summarised below.

First, this thesis contributes to the conceptual development of DfSS in DF4D. Whilst DfSS appears in the literature, the concept is used with little precision or clarity. Furthermore, the lack of a contextually appropriate understanding of DfSS is hindering the success of DF4D projects. This thesis goes beyond existing literature on DfSS to identify the relevant principles of DfSS in the DF4D context.

Second, this thesis advances the practical development of DfSS in DF4D. There is no support available for practitioners to DfSS in DF4D and this is contributing to the failure of DF4D projects. This thesis results in a normative framework to support DfSS which can be used during the planning and evaluation of DF4D projects. It also develops an initial toolkit to support DfSS by mapping the networks of DF4D projects. This toolkit can be used during an ongoing intervention to complement the DfSS framework.

Finally, this thesis has clarified the value of using an analytical and a critical systems approach. This study expands on prior work to clearly explain why and how these approaches are complementary in studying complex socio-technical systems. It sets out their distinct ontological positions and shows that ontological pluralism is a useful way of tackling complex societal problems. It provides an example of ontological pluralism that can serve as a reference point for other studies.

8.4 Limitations

This thesis has significantly advanced our understanding of DfSS in DF4D. However, there are some limitations which must be considered to guide interpretation of the findings.

First, it is worth alerting the reader to the potential limitation of repeatability. According to Robson & McCartan (2016), issues of bias and rigour exist in all flexible design research, particularly when dealing with qualitative data where the researcher is the main ‘instrument’ through which information is mediated. Whilst care has been taken to explain the exact steps in the interpretation of the data, it is not expected that replication by another researcher would result in exactly the same findings. To quote Linderman (2012) again, "*when you think differently, you perceive differently*." In other words, our own beliefs and knowledge influence the way that we understand and make sense of the world. As much as possible, the researcher has declared this position whilst also taking steps to mitigate against potential bias. Data triangulation was used in the study to include the analysis of interviews, reports, observations and graphical (network) representations. Methodological triangulation was used to integrate qualitative and quantitative analysis. Finally theory triangulation was used to combine both analytical and critical systems perspectives. Whilst, exact repeatability might not be possible, validity has remained a central concern of this study.

Second, the potential limitation of generalisability has not escaped notice. The main findings in this thesis have been developed by closely analysing three DF4D projects in the healthcare sector. The generalisability of the findings beyond these cases is unknown, however emphasis is placed on analytical not statistical generalisability. It should also be noted that the case studies have been selected from different geographies and institutions, which may go some way to quell doubts about the generalisability of these findings. Earlier it was also speculated that the main practical outcomes of the thesis (the DfSS framework and Designet toolkit) could be relevant for other contexts beyond DF4D. Further work is clearly needed to clarify this potential.

The third limitation in this study is related to participant access, a well-known challenge in research. Specifically, in the analytical study it was not possible to interview stakeholders outside of the design team (e.g. donors, end users and beneficiaries) in the first case study. In the critical systems study, only members of the design team participated in the workshops. The lack of engagement from actors outside of the design team partly undermined the emancipatory agenda of the research, which aimed to give a voice to disadvantaged actors. Despite this, the workshops were still able to draw attention to the inequitable relationships between the members of the design team and the other actors not present. Consequently it was found that the lack of participation, whilst a limitation, did not undermine the validity of the findings.

The final limitation is one which has already been alluded to several times. Unavoidably this research on the Global South originates from a Northern perspective, and is thus restricted by the inherent world view that this imposes. Whilst the researcher has made efforts to give a voice to the affected actors in DF4D, it does not claim to speak for them. The researcher squarely acknowledges this conflict and hopes that it encourages more studies on DF4D from a broader perspective.

8.5 Future research

This thesis has helped to advance our understanding of DfSS in DF4D, an emerging phenomenon in the humanitarian and aid sector. It has revealed several promising areas for further research that are outlined below.

First, future work could explore the application of the DfSS framework to positively shape the direction of a DF4D project. In this study the framework has identified sixteen criteria to advance DfSS in DF4D. It has been used in this thesis to evaluate three healthcare projects, however the findings suggest that it could also provide useful support in the planning stages of DF4D projects. Future work could implement the framework at the start of a real-world intervention in order to assess its impact on DfSS. Its application could be tested in DF4D projects, and indeed in other projects in the aid sector.

Second, the development of Designet into a final tool would be a valuable elaboration of this study. In this thesis, Designet has laid the conceptual foundations for a tool, however further work is needed to demonstrate proof of its impact and to validate it as a tool. Future research could explore using Designet in an ongoing DF4D project from its inception. It could also explore its application in other settings beyond DF4D, for example with humanitarian/development or sustainability projects in both the Global North and South.

Third, future research could focus on the linkages between DfSS and the field of sustainability transitions. The discussion showed that theory on sustainability transitions could help to better understand and explain DfSS in DF4D. It also suggested that DfSS could enrich existing theory on sustainability transitions by adding an important social dimension. The mutual benefits of these perspectives could be further investigated. Discussion on the Multi-Level Perspective in Chapter 7 also highlighted several areas that require more attention. Considering the interrelated analytical levels of the niche, regime and landscape, the following questions could help to shape future research on DF4D: how can the transformative potential of niches be supported? What are the most promising types of niches? How might these niches become connected and create a new field? How might the existing regime become destabilised? What are the possible transition pathways? How does the geospatial identity of DF4D projects influence these transitions?

Finally, there is a need for additional studies on DfSS in DF4D from a post-colonial/decolonial perspective. In this respect, promising avenues for research could include the exploration of alternative epistemologies such as Buen Viver ("Good Living") an indigenous South American philosophy that is concerned with social justice and ecological equality; Ubuntu, a South African concept focused on oneness and collective humanity; Harambee, an East African tradition of community action; and, Swaraj, an Indian concept popularised by Mahatma Ghandi that places emphasis on self-governance and community building. The relevance of these epistemologies of the South to design, and specifically their relevance to DfSS in DF4D could be a fruitful investigation.

8.6 Summary

This chapter has summarised the thesis and identified its key contributions, limitations and areas for further research. Overall, this study has contributed to the conceptual and practical development of DfSS in DF4D. Previously, DfSS was an ill-defined and poorly understood concept. This study has helped to clarify the principles of DfSS, and formulated a contextually appropriate version of DfSS in DF4D. The framework and initial toolkit offer a practical way forward for DfSS in DF4D. Future research could develop these into fully validated tools, through iterative cycles of testing. Additional research is also needed to clarify the role of DfSS beyond the project-level, and to add much-needed post-colonial/decolonial perspectives. This chapter has highlighted that ontological pluralism has a lot to offer in the study of complex societal problems, and that integrating analytical and critical systems approaches is a fruitful pursuit in tackling socio-technical systems. The researcher hopes that the contributions in this thesis might genuinely make a difference to the success of DF4D projects, and more broadly positively impact social sustainability in the aid sector.

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Appendix

Appendix Table 1 – Interview protocol to identify themes of DfSS in DF4D

Subjects	Questions
Designers, project managers and technical staff. *Project manager (CS1-01), Designer (CS1-02), Designer (CS1-03), Junior designer (CS1-04), Junior designer (CS1-05), Project lead and engineer at BETiC (CS2-01), Physiotherapist at BETiC (CS2-02), Designer at BETiC (CS2-03), Junior designer at BETiC (CS2-04), MakerSpace manager and designer (CS3-01), Lead designer at MakerSpace (CS3-02), Designer at MakerSpace (CS3-03)*	**1. Introducing the research, clarifying definitions and answering queries*.*** 1.1 "My research is exploring how to Design for Social Sustainability. Sustainability is often described as a way to meet people's needs now without compromising the ability of future generations to meet their needs. Normally people talk about sustainability in terms of economic, environmental and social sustainability. 1.2 My research focuses on *social* sustainability. Social sustainability is concerned with the human wellbeing and flourishing of society now and in the future. From now on, when I talk about sustainability I will be referring to social sustainability. 1.3 Do you have any questions?" **2. Exploring DfSS for DF4D. During the interview, the interviewee's responses are cross-checked against the themes found in literature.** 2.1 What is a sustainable project? 2.2 What is not a sustainable project? 2.3 How do you make sure that the project you are designing is sustainable? 2.4 What are some of the potential barriers to sustainability? Why do these exist? 2.5 Do you think [DF4D project] will be sustainable in the future? Why? 2.6 What are some of the potential risks to the sustainability of [DF4D project]? Why do these exist? How could you overcome these? **3. Further discussion on DfSS for DF4D. Prompt interviewees to speak about themes found in literature which have not been mentioned already.** 3.1 How important is [e.g. "a systemic approach", "empowerment" etc.] to the sustainability of [DF4D product case study]?

Appendix Table 2 – Interview protocol to evaluate the case studies

Subjects	Questions
Designers, project managers and technical staff. *Project manager (CS1-01), Designer (CS1-02), Designer (CS1-03), Junior designer (CS1-04), Junior designer (CS1-05), Project lead and engineer at BETiC (CS2-01), Physiotherapist at BETiC (CS2-02), Designer at BETiC (CS2-03), Junior designer at BETiC (CS2-04), MakerSpace manager and designer (CS3-01), Lead designer at MakerSpace (CS3-02), Designer at MakerSpace (CS3-03)*	**1. General information** 1.1 Can you tell me about your role at [organisation]? 1.2 When did you start working at [organisation]? 1.3 What is your experience/ background working in this sector? **2. DF4D product** 2.1 Can you describe the problem you are trying to solve? 2.2 What is the problem with the existing product? 2.3 How does the DF4D product solve this problem? 2.4 If at all, what would you like to change about the digitally fabricated product? **3. DF4D process** 3.1 What is different about the design process in a DF4D project compared with a conventional humanitarian/ development project? 3.2 Can you describe the design process? Prompts: • How did the project start? • How do you select and prioritise projects? • How do you gather data and conduct user research? • What sort of interaction do you have with users and stakeholders during the design process? When do you interact with them? • During the concept development, what type of information do you use to inform the process? • How do you measure impact? What criteria do you use to evaluate the product is satisfactory? How do you collect this data? **4. Perceptions of DF4D** 4.1 How does digital fabrication affect your work? 4.2 What are the advantages of using digital fabrication tools in the humanitarian/ development sector? 4.3 What are the disadvantages of using digital fabrication tools in the humanitarian/ development sector?
Partners. *CEO at RNCT (CS2-05), Prosthetist and Orthotist at RNCT (CS2-06), Production technician at RNCT (CS2-07), Production technicians at RNCT (CS2-08), Technical consultant at BMVSS (CS2-12), Prosthetist and Orthotist at BMVSS (CS2-13), Technician at Jaipur Foot (CS2-14), Project manager at BMVSS (CS2-15), Secretary at BMVSS (CS2-16), Project manager at KNH (CS3-04), Project administrator at KNH (CS3-05), Project data manager at KNH (CS3-06),*	**5. General information** 5.1 Can you tell me about your role at [organisation]? 5.2 When did you start working at [organisation]? 5.3 What is your experience/ background working in this sector? **6. DF4D product** 6.1 What is the problem with the existing product? 6.2 How does [DF4D project] solve this problem? 6.3 Do you think [DF4D project] will be sustainable in the future? Why? 6.4 What are some of the potential risks to the sustainability of [DF4D project]? 6.5 If at all, what would you like to change about [DF4D project]? **7. DF4D process** 7.1 Can you describe how you have participated in the project? Prompt: • How has your participation influenced the project? **8. Perceptions of DF4D** 8.1 How does digital fabrication affect your work? (if applicable) 8.2 What are the advantages of using digital fabrication tools in the humanitarian/development sector?

Biomedical engineer at KNH (CS3-08)	8.3 What are the disadvantages of using digital fabrication tools in the humanitarian/development sector?
Users of DF4D products. *Beneficiary 1 at RNCT (CS2-09), Beneficiary 2 at RNCT (CS2-10), Deputy head nurse at KNH (CS3-07)*	**9. General information** 9.1. For practitioners, questions on role/experience. 9.2. For beneficiaries questions on age/employment. **10. DF4D product** 10.1 How long have you been using the existing (non-DF4D) product for? 10.2 What is the problem with the existing product? 10.3 How does the digitally fabricated product solve this problem? 10.4 If at all, what would you like to change about the digitally fabricated product? **11. DF4D process** 11.1 Can you describe how you have participated in the design process? Prompt: • How has your participation influenced the project?
Users of alternative (non-DF4D) products. *Beneficiary 1 at BMVSS (CS2-17), Beneficiary 2 at BMVSS (CS2-18), Beneficiary 3 at BMVSS (CS2-19), Beneficiary 4 at BMVSS (CS2-20), Beneficiary 5 at BMVSS (CS2-21), Beneficiary 6 at BMVSS (CS2-22)*	**12. General information** 12.1. For beneficiaries questions on age/employment. **13. Alternatives to DF4D** 13.1. How long have you been using [the non-DF4D product] for? 13.2. How does using this product affect your daily life? 13.3. If at all, what problems do you find with the existing product? 13.4. If at all, what would you like to change about this product?

Appendix Table 3 – Flaticon attributions for Designet toolkit

Designet card/counter	**Attribution**
Beneficiary, implementor, influencer, initiator, machine producer, material supplier	Icon made by Gregor Crsnar from www.flaticon.com
Designer	Icon made by Eucalyp from www.flaticon.com
Donor, partner, volunteer, government	Icon made by Prosymbols from www.flaticon.com
End user	Icon made by Prosymbols from www.flaticon.com
Maker	Icon made by Eucalyp from www.flaticon.com
Digital fabrication tool	Icon made by Freepik from www.flaticon.com
Digital design tool	Icon made by Freepik from www.flaticon.com
Hand tools	Icon made by Vectors Market from www.flaticon.com
Non digital powered machinery	Icon made by Eucalyp from www.flaticon.com
Technology platform	Icon made by Smashicons from www.flaticon.com
Design sketches & models	Icon made by Smartline from www.flaticon.com
Document	Icon made by Becris from www.flaticon.com
Prototype, finished product	Icon made by Freepik from www.flaticon.com
Use context	Icon made by Freepik from www.flaticon.com
Production context	Icon made by Freepik from www.flaticon.com
Design context	Icon made by Smartline from www.flaticon.com
Money	Icon made by Dave Gandy from www.flaticon.com

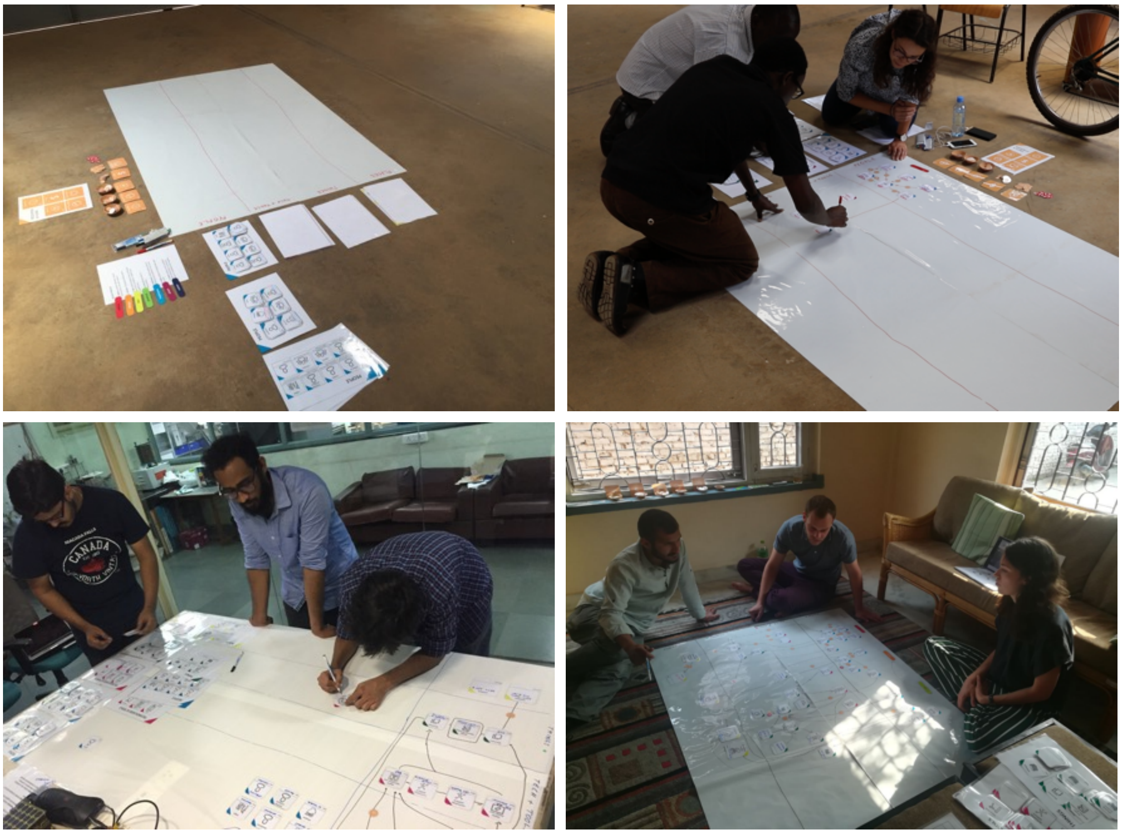
Material	Icon made by Freepik from www.flaticon.com
Information	Icon made by Freepik from www.flaticon.com
Knowledge	Icon made by Freepik from www.flaticon.com
Intangible	Icon made by Freepik from www.flaticon.com
Challenge	Icon made by Freepik from www.flaticon.com

Appendix Table 4 – Designet workshop protocol

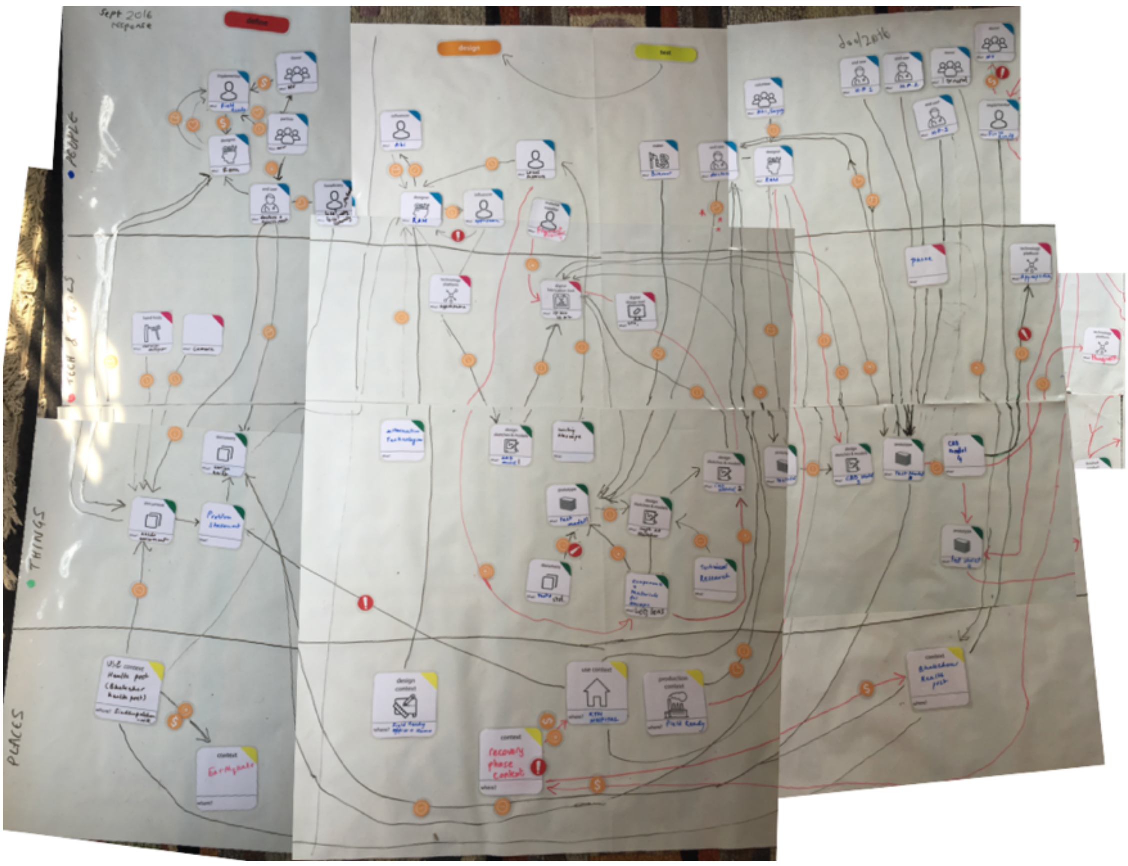
Mins	**Step**	**Overview**	**Script**
15	1	Set up cards, white board paper and the pens.	
10	2	Start of workshop. Introduce the aims of the workshop.	The aim of this workshop is to build up a shared understanding of the [DF4D project]. As you know, this project involves the complex interaction of many different elements – people, objects, technologies and the broader context. Today we will map these different elements and their interactions during the different stages of the project. We can call this map a network. During this workshop, we will reflect on how this network advances social sustainability – in other words, how the [DF4D project] supports the human wellbeing and flourishing of society, now and in the future. From now on, when I am talking about sustainability, I will be referring to social sustainability. There will be opportunities to reflect on challenges faced during the project and to envision what the project might look like in the future.
	3	Confirm consent and start recording.	I would like to record this workshop for my PhD thesis and potential publications. Please confirm that you consent to this and return the consent forms to me.
	4	Explain the stages of the design process.	The design process consists of several different stages, starting with define, design, test, produce, implement, adopt and sustain. Today, we will map the [DF4D project] for each of these stages in turn. [Provide clarification of stages of design process if necessary.]
	5	Answer any questions.	Before we start, do you have any questions?
	6	Identify current stage in the design process.	Which stage of the design process is the [DF4D project] currently at?
20	7	Define the people involved in the first stage of the design process (define).	To begin with we will focus on the first stage of the design process, define. We will list who is involved in this stage. [Present people cards] To help there are these people cards. At the top of each card is the person's role and at the bottom is a blank space for you to describe who they are. For example, [the implementer] is [Field Ready].

Mins	Step	Overview	Script
			Some of the cards are blank for you to assign new roles if you need to. [Clarify definitions if necessary] *Prompts:* who is involved in the define stage? who initiates the design process initiated?
	8	Define the technology and tools involved in the first stage of the design process (define).	Next we are going to list the technologies and tools that are used in the define stage. [Present technology and tools cards, clarify definitions if necessary] *Prompt:* Which technologies or tools do you use in the define stage?
	9	Define the things involved in the first stage of the design process (define).	Next we are going to list the things that are created in the define stage. [Present things cards, clarify definitions if necessary] *Prompt:* What things are created in the define stage?
	10	Define the places involved in the first stage of the design process (define).	Next we are going to list the places where the define stage takes place. [Present places cards, clarify definitions if necessary] *Prompt:* Where does the problem definition happen?
	11	Draw connections between actors.	Now we are going to draw lines between these elements to show the interactions between them. You can use arrows to show the direction of these interactions and you can use dotted lines if you think the interactions are weak. You can think about these interactions as flows of resources. These might be tangible, like flows of money and materials. Or intangible, like information and knowledge. They can also represent other intangible values, like trust, respect and care. [Clarify definitions and give example if necessary]. Please can you draw the interactions between the different actors and use these counters to describe these interactions?
	12	Take photos of maps.	
20-50	13	Repeat steps 7-12 for subsequent stages of the design process.	
30	14	Reflect on how the current network advances/ limits social sustainability.	Looking at the network as a whole, which actors or interactions do you think are important for advancing the sustainability of the project, and ultimately the positive social impact of [DF4D product]? Which actors or interactions are potential barriers to the sustainability of the project, and ultimately limit the positive social impact of [DF4D product]?

Mins	Step	Overview	Script
	15	Reflect on challenges faced during the design process.	Where do you face challenges in the current design process? Please mark these with the challenge counters. What do you think could be done to overcome these challenges?
	16	Reflect on future stages of the DF4D project.	Imagine if you were to map the future stages of the [DF4D project]. What would the network look like? What do you think would be different about the actors and interactions involved compared with the current map? *Prompts:* Would any new people/technologies and tools/things/places be involved? Would any people/technologies and tools/things/places no longer need to be involved? What would be different about the connections between these actors?
10	17	Gather feedback on the design mapping workshop.	Thank you for participating in this workshop. Before I close the session, I would like your feedback on mapping the design process. *Prompts:* How did the workshop impact your understanding of the [DF4D project]? How did it impact your understanding of the different actors and their interactions? How did it impact your understanding of activities that potentially advance or limit the sustainability of the project? How did it impact your ability to recognise challenges and ways to mitigate them? How did it impact your ability to imagine the future stages of the [DF4D project]? How did you find using the visual tools (cards and counters)? What would you change about the mapping process?



Appendix Figure 1 – Using Designet toolkit with the case studies



Appendix Figure 2 – Network of 3D printed otoscope (Case Study 1)

Appendix Figure 3 – Network of digitally fabricated leg prosthesis (Case Study 2)

Appendix Figure 4 – Network of digitally fabricated suction pump machine (Case Study 3)