50 Years of Inclusive Design for Childhood Mobility; Insights from an Illustrative Mapping Review

Cara O'Sullivan[a*], Farnaz Nickpour[a]

[a] University of Liverpool
*Corresponding author e-mail: cara1@liverpool.ac.uk

Abstract: In recent years, the field of Inclusive Paediatric Mobility (IPM) has gained increasing interest from a variety of disciplines and stakeholders, including designers and engineers, healthcare professionals, policymakers, children and families. This has led to increased visibility and understanding, as well as the development of new products and services. However, knowledge around IPM design remains fragmented and with many issues around the desirability, feasibility, and viability of interventions. This is the first illustrative mapping review of the IPM design field to capture, classify, and analyse IPM design contributions chronologically over the past five decades. The review explores relationships between contributions, their context, and their significance in the landscape of IPM at the time. This paper outlines insights from the mapping review and highlights key trends, gaps, and issues in the IPM design field since 1970. Key themes and considerations are proposed for a framework to improve the future of IPM design.

Keywords: Inclusive Design, Childhood, Disability, Mobility, Mapping Review.

1. Introduction to Inclusive Paediatric Mobility

The contemporary landscape of Inclusive Paediatric Mobility (IPM) design saw negligible change until the introduction of the first paediatric power wheelchair in the United Kingdom in 1983. It was around this time that the widely accepted narrative used to address paediatric mobility disabilities began to evolve. Conventionally, the acknowledged goal was to 'normalise' children's movement, with walking being the ultimate achievement. The stark lack of independence-promoting IPM interventions other than walking aids at this time, was simply a reflection of society's thinking (Wiart & Darrah, 2009). This mentality shifted in the late 1970s, to a narrative of encouraging children to use their most efficient mobility approach to optimise their experience of childhood (Butler, 2009). Interest in the field has since continued to grow from designers, engineers, healthcare professionals and families. This has led to increased knowledge and understanding of the need for IPM interventions from an early age (Rosen et al., 2017), as well as evolutions in narrative and the development of new IPM products and services (Logan et al., 2017). From walking aids and prosthetics to wheelchairs and exoskeletons, there remains a myriad of challenges around the desirability, feasibility and viability of existing paediatric mobility products, in addition to poor documentation of design processes, principles, accomplishments and failures within the field.

This paper maps and synthesises findings from the perspective of Inclusive Design, in order to highlight gaps, issues and patterns and translate these into constructive points for consideration in future IPM design processes. The aim is to learn from IPM history and to question its present, in order to capture core elements of a design framework to guide the future of IPM. Such a framework will need to be adaptable in order to operate in a multitude of evolving social and technological future contexts. This highlights the fact that IPM design embodies and reflects not only the state of technology and healthcare, but also social, political, economic, legal and environmental states. Subsequently, each design contribution is entwined with context-specific projections which need to be captured and acknowledged.

2. Understanding IPM Design; What, Why, Who?

2.1 What is Inclusive Paediatric Mobility Design?

IPM design is the application of an inclusive design approach to create mobility interventions such as wheelchairs, walking aids and exoskeletons, with the fundamental goal of optimising the experience of childhood. Inclusive Design centres on the diversity of users' physical and psychosocial needs (Lim et al., 2016) and often starts with considering 'extreme' or 'extra-ordinary' users (Newell & Gregor, 1997). In the context of commercially available mobility interventions, young children are the most underserved and excluded age group of users (Feldner et al., 2016); hence becoming the 'extreme' of an already 'extreme' user group. Designs which cater for the particular needs of people with disabilities are conventional examples of Inclusive Design (Nayak et al., 2016). There are three predominant approaches to the application of inclusive design (Clarkson & Coleman, 2015), and it is important to consider all three in order to build a comprehensive, accurate and critical picture of the IPM design landscape. Table 1 provides examples of IPM interventions categorised by their most commonly used inclusive design approach.

Table 1. Inclusive design approaches commonly used for paediatric mobility interventions.

USER-AWARE DESIGN APPROACH	CUSTOMISABLE OR MODULAR DESIGN APPROACH	SPECIAL PURPOSE DESIGN APPROACH
Tricycles	Ride-On Scooters	Wheelchairs (Power/Manual)
Go-karts	Ride-on toy vehicles	Splints and Casting (to support or stretch muscles/bones)
Pushchairs, Strollers, Buggies	Tailored therapy and physical training equipment	Walking aids (i.e. crutches, canes, gait trainers, walkers, exoskeletons, prosthetics)

2.2 Why IPM Design Matters; Issues and Opportunities

SIGNIFICANCE. Mobility, as well as being a human right, is a necessary and significant part of life which, amongst children in particular, impacts multiple health outcomes. Independent mobility facilitates children's physical, emotional, psychosocial, perceptual and cognitive development (Nilsson et al., 2011), as well as providing opportunities to make social

interactions (Guerette et al., 2013) and increase confidence and participation with peers in everyday activities (Casey et al., 2013). For infants and children with mobility disabilities, opportunities to develop in these areas are greatly reduced and the likelihood of developing passive, dependent behaviour increases significantly (Durkin, 2002). Hence, IPM interventions are instrumental in enabling independent mobility and helping children to develop to their full potential. The early years of childhood are characterised by rapid and critical developments of the brain which provide the essential building blocks for future growth, development and progress. Around 90% of brain development happens during the first five years of life (Brown & Jernigan, 2012), making early intervention and provision of IPM an urgent priority to avoid irreversible developmental delays. Provision of powered mobility to those who lack it, has been shown to facilitate childhood development from as young as 11 months old (Rosen et al., 2017).

ISSUES. There are a myriad of unresolved issues around the design of IPM products currently available in the market. Many of these act as barriers for incorporating IPM into a child's life. Many IPM interventions are as restrictive as they are enabling and often exclude children with complex needs. Furthermore, they lack up-to-date integrated and assistive technologies, let alone desirability and childhood appeal which has long been the norm in other sectors. Hence, issues around IPM designs can be classified under three meta-levels:

1. Desirability (i.e. acceptability, pleasurability, emotional durability and personal meaning (Desmet & Dijkhuis, 2003)).
2. Feasibility (i.e. usability, technicalities, functionality/features (Livingstone & Paleg, 2014))
3. Viability (i.e. economies of scale, affordability, sustainability (Rushton et al., 2015))

While each issue has been separately investigated and addressed within adult services (Leaman & La, 2017), there is a considerable lack of holistic, convergent and innovative thinking within paediatric services (Feldner et al., 2016).

OPPORTUNITIES. IPM is a global need, as well as a worldwide market (Casey et al., 2015). Recent initiatives in the wider area of disability and inclusive technologies have aimed to reduce the gap between the current state of design, development, manufacture and adoption of IPM products, with innovations in design, technology, materials and manufacturing processes as seen in other sectors (Nesta, 2014; Google Impact Challenge, 2015; Toyota Mobility Foundation, 2018). Moreover, there are emerging scholarly attempts at converging disability, design and innovation through new postgraduate courses (Global Disability Innovation Hub, 2019). Thus, there exists a timely opportunity to develop a framework to inform and equip the next generation of IPM designers with foundational knowledge, processes and tools to better steer progress and accelerate learning in the field globally.

Advanced manufacturing technologies such as 3D printing, combined with the advent of social product development, crowdfunding and open source movements (providing platforms to share and build upon designs and), provide a significant opportunity for continued development, full customisation and viable route to market for IPM products

(Lunsford et al., 2016). Furthermore, open source design platforms welcome new players to the industry by saving time and money on research and development, and unleashing creativity and tools to drive rapid innovation for IPM at a global scale (Manero et al., 2019).

Alongside such engineering and socio-technological advancements, there is an imperative to advance IPM design knowledge base and critical discourse around narratives and experiences of disability, childhood and mobility. The narratives and philosophies adopted by Childhood Studies, Mobility Design, and Critical Disability Studies are evolving at a rapid pace and would be instrumental in progressing the field of IPM design if integrated in an interdisciplinary and holistic manner. Such opportunity needs a transdisciplinary, human centred and participatory approach in order to ensure various disciplines and stakeholders are engaged. The ability to facilitate inclusive and interdisciplinary participation is known to: enable a more holistic perspective on problems and potential solutions, offer co-creation opportunities, give choice and agency to end-users, and result in products which better match the individual needs of users (Thorsen et al., 2019).

From the perspective of health economics, there lies an opportunity to build a case for state provision of early IPM interventions and potential funding for further research and development in the field of IPM design. Children who receive adequate developmental opportunities during early childhood, have a better chance of becoming healthy and productive adults, which can reduce future costs of education, medical care and other social spending (Bray et al., 2017).

Looking to the future of childhood mobility, there are opportunities for the wider use of user-aware and customisable design approaches. These could facilitate the move towards a truly inclusive experience of childhood, by optimising mobility-related participation for all children.

2.3 IPM Design Stakeholders; Expert Fields and Missing Voices

The narratives, definitions, and priorities of IPM design evolve and vary across different cultures and stakeholder groups: to provide functional, timely and energy-efficient mobility (Butler 2009); to meet developmental and gross motor milestones (Kenyon et al., 2018); to provide a safe means of mobility that can track a child's progress and enhance their mobility experience (Soh & Demiris, 2012); or to enable independence and meaningful participation in life (Pituch et al., 2018). Each of these priorities reflects a single disciplinary perspective (i.e. Occupational Therapy, Psychology, Parents, Design and Engineering).

The importance of taking a multifaceted approach to IPM has been long established (Field 1999), as well as the need for holistic stakeholder input to take into account a range of views and lived experiences (Livingstone, 2010). However, this is not fully reflected in the IPM design field and the actual design and development of IPM interventions. There remain numerous scholarly fields, disciplines, experts and stakeholders whose voices are currently missing, and could bring significant value, as well as complexity, to the IPM design process. The subject areas most commonly drawn upon for knowledge during the IPM design process include Childhood, Disability, Mobility, and Design. These areas could be viewed as the

foundations of the IPM design field, with other subject areas surrounding and overlapping them at different stages of the design process. Considering the diversity of narratives from different stakeholder groups, it would be valuable to explore and capture stakeholder knowledge and voices from within and between these four overarching spheres. This could be a good starting point for incorporating more thorough interdisciplinarity into the IPM design process.
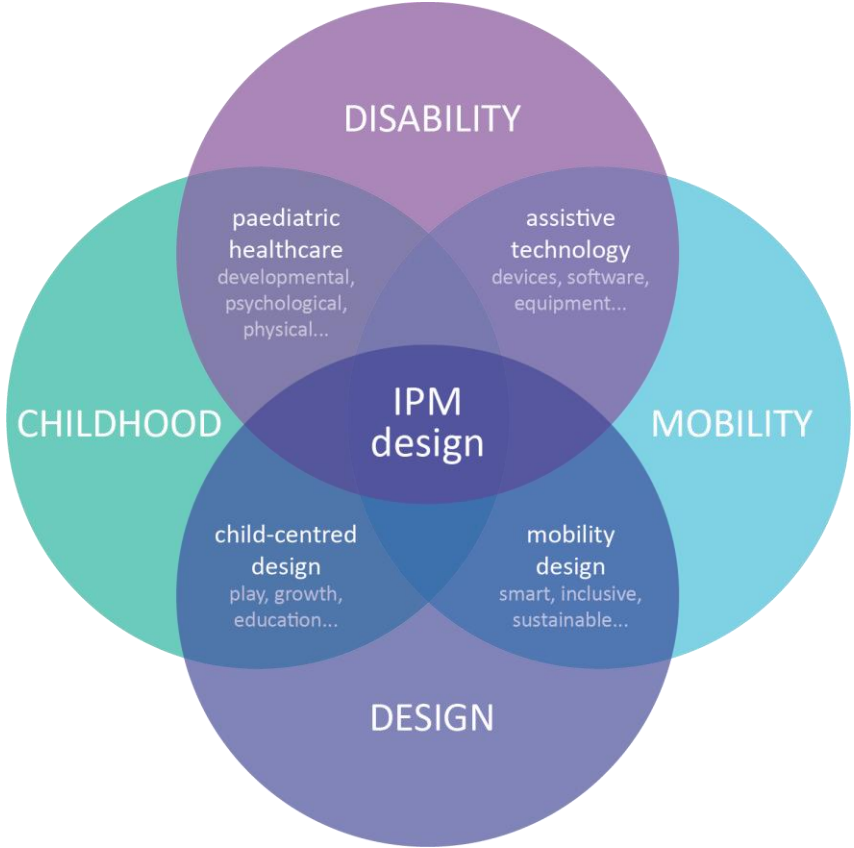

Figure 1. The four foundational disciplinary fields of IPM design.

3. Aims of the Designerly Mapping Review

The purpose of conducting this designerly mapping review is twofold: to thoroughly capture and to clearly illustrate the changing landscape of IPM. Such review is pivotal in informing the direction and dimensions of an IPM design framework aimed to impact and improve the way IPM interventions of the future are designed. Hence, it is essential that this review comprehensively captures the core elements to be included in such a framework (O'Sullivan and Nickpour, 2020). An examination of the field needs to encompass past and present perspectives, in order to identify failing, successful, missing, or complicated elements within the past and present landscape. Additionally, such a map should enable moving beyond the present by providing insights on how an ideal IPM future could look, and what should be considered to move towards this. Three distinct aims of conducting a mapping review of the IPM design field include learning from history, questioning the present and road mapping the future.

4. Methodology & Methods

4.1 Methodology

A comprehensive list of various types of literature review (Grant & Booth, 2009) was carefully reviewed. As a result, a representative evidence mapping review was chosen, in order to objectively categorise contributions by their key features. This type of review enables the identification of gaps in knowledge or need for future research, and presents results in a clear visual format (Miake-Lye et al., 2016). The mapping review data is presented chronologically to allow for identification of trends, clusters and deserts across all types of designerly contributions through history. Mapped contributions are then critically analysed to evaluate quality and significance, as well as their relationship to other contributions on the map. This methodology was selected as it allows many different types of designerly contributions to be plotted at a high level of granularity using the same categories, thus enabling a holistic visualisation and analysis of the field (Jahan et al., 2016), which is currently missing, and much needed. Data for the review is classified under one of four types of designerly contributions. Four levels were chosen as they encapsulate all types of designerly contributions to the field of IPM (Wobbrock, 2016). Table 2 outlines the contribution classification system.

Table 2. Classification of IPM Design Contributions.

I (INTERVENTIONAL)	T (THEORETICAL)	M (METHODOLOGICAL)	E (EMPIRICAL)
New or improved products, services, systems, or artifacts. **I.1 -** Intervention was implemented or commercialised. **I.2 -** Interventions remained a concept or prototype.	Conceptual models, frameworks, policies, principles or important variations on those that already exist (e. g. disability studies).	Novel or refined methodologies, methods, processes, or techniques with sufficient detail to be replicated by others.	Data sets, surveys, arguments or findings based on empirical research which reveal formerly unknown insight and analysis of behaviours, capabilities, or interactions with interventions, etc.

Table 3 translates mapping review objectives into high level mapping questions. These will guide the collection of data and help achieve the aims i.e. to learn from history, to question the present and to roadmap the future.

Table 3. Mapping Review Objectives and Questions.

OBJECTIVE	ID	MAPPING QUESTION (MQ)
Identify levels and types of design contributions.	MQ1	What is the type of design contribution? i.e. I.1, I.2, T, M, E (CLASSIFICATION)

Identify if design contributions have increased/decreased/fluctuated/remained constant throughout history.	MQ2	When have designerly contributions been made to the field of IPM? (YEAR)
Identify the balance of contributions from stakeholder groups and explore diversity of perspectives and types of contribution.	MQ3	Which discipline or stakeholder group does the contribution come from? (CONTRIBUTOR)
Identify where in the world IPM contributions have come from and why.	MQ4	Where have designerly contributions been made to the field of IPM? (GEOGRAPHY)
Understand the design approach and how this influences the success of the contribution.	MQ5	Which Inclusive Design approach has been used to develop it? i.e. 'User Aware', 'Customisable/modular', or 'Special Purpose' (DESIGN APPROACH)

4.2 Methods

The data collection search protocol centred on electronic database searches to identify evidence of contributions made between 1970 and 2020. Search databases included: Compendex, Scopus, PubMed, Web of Science, Science Direct, Google Scholar, Google Images, and Open Grey. Each result was reviewed according to the criteria outlined in Table 4. To capture grey literature, unpublished fieldwork and artefacts, IPM experts (each with a minimum of 15 years of experience in their field) were shown the results and asked to share any further known contributions. This included four paediatric therapists and four paediatric mobility designers.

Search strings were a combination of keywords relating to childhood, mobility, and design categories as follows: "childhood" OR "child" OR "children" OR "early years" OR "infants" OR "paediatric" OR "pediatric" AND "mobility" OR "assistive mobility" OR "power mobility" OR "powered mobility" OR "power chair" OR "power wheelchair(s)" OR "power wheelchair(s)" OR "wheelchair(s)" OR "walking aid" OR "exoskeleton" AND "design" OR "designing" OR "development" OR "implementation" AND "disability" OR "impairment".

Table 4. Inclusion and Exclusion Criteria.

INCLUSION CRITERIA	EXCLUSION CRITERIA
Contributions post 1970 *(IPM design field emerges around this time).*	Interventions which do not provide a means of *independent* mobility (e.g passive mobility via attendant).
Novel or significant designerly contributions (i.e. excluding incremental updates and copycat products)	Contributions which lack record of the context of their creation.
Contributions that relate to at least one child aged ≤18 years with a mobility disability.	Studies involving only non-disabled/fully mobile children or adults.
The development of technologies and gadgets specifically for the IPM field.	Non-English language publications (with no English translation available).

4.3 Limitations

Searches were carried out in English language. The likelihood of excluding eligible contributions documented in languages other than English may significantly skew geographic observations, in the context of this illustrative review. The majority of contributions were collected from grey literature searches which are typically less thorough than traditional systematic searches of academic literature (Turner et al., 2005). This could be seen as a finding in itself, reflecting the nature of IPM contributions and their documentation. The decision-making process around novelty and/or significance of a contribution could be a limitation as it was judged based on other existing designerly contributions in the IPM landscape at the time, and whether the differences were distinct enough to describe and record.

5. Results and Key Findings

5.1 Data Collection Results

Tables 5, 6, 7, 8 and 9 present the identified IPM design contributions between 1970 and 2020. Contributions are categorised under four types including Interventional, Theoretical, Methodological, and Empirical (see Table 2). Interventional contributions are presented under two separate tables depending on whether they were successfully commercialised (Table 5) or remained as a concept (Table 6). All contributions are referenced numerically in the order they appear in the tables, with their sources listed in the appendix to distinguish them from other references.

Table 5. Interventional Contributions (I.1) which made it to market or were commercialised.

MQ1 - **I.1**					
	CONTRIBUTION NAME	MQ2 **YEAR**	MQ3 **CONTRIBUTOR**	MQ4 **GEOGRAPHY**	MQ5 **DESIGN APPROACH**
1980s	Turbo / BobcatDX power chair - Everaids [1]	1984 - 1990	Engineer/Parent	UK	Special Purpose
	Aug-mentative mobility aid 'Smart Wheelchair' - CALL Centre [2]	1988	Designer/Engineer	UK	Special Purpose
1990s	Mobility equipment Service - WhizzKidz [3]	1990	Healthcare/ Philanthropist	UK	Special Purpose
	The CooperCar -RJ Cooper & Associates [4]	1992 - 2000	Psychologist/ Engineer	North America	Customisable or Modular
	BIME infant & junior bugs - Designability [5]	1993 - 2006	Engineer	UK	Special Purpose
	GoBot - Lucile Packard Hospital Stanford [6]	1995	Healthcare	North America	Special Purpose

	Tiro training chair-Lisbeth Nilsson and Permobil [7]	1996 - 2005	Healthcare	Sweden	Special Purpose
2000s	Bugzi beginners power chair - MERU charity [8]	2005	Designer	UK	Special Purpose
	Dragon power chair - Dragon Mobility [9]	2005	Engineer/Parent	UK	Special Purpose
	Permobil Koala power chair [10]	2006	Designer/Engineer	Sweden	Special Purpose
	Wizzybug power chair - Designability (BIME) [11]	2007	Designer	UK	Special Purpose
	Balder Junior power chair - Etac [12]	2007 - 2015	Engineer	Sweden	Special Purpose
	Zippie Salsa M2 mini - Sunrise Medical [13]	2008	Engineer	North America	Special Purpose
	Skippi power chair - Ottobock [14]	2009	Engineer	Germany	Special Purpose
2010s	Self-initiated prone progressive crawler - Virginia c University [15]	2010	Engineer	North America	Customisable or Modular
	TinyTrax power chair - Imaginable Ltd [16]	2011	Designer/Engineer	UK	Special Purpose
	Drive Deck wheelchair platform - Smile Smart Technology [17]	2011	Engineer	UK	Special Purpose
	AKKA Mobility Platform JCM Helsingborg [18]	2011	Healthcare	Sweden	Customisable or Modular
	Systems Collision Avoidance Device (SCAD) - Chailey Heritage [19]	2012	Engineer	UK	Special Purpose
	Go-Baby-Go toy car adaption Service [20]	2012	Healthcare	UK	Customisable or Modular
	Spectra Blitz power chair - Invacare [21]	2012-2018	Engineer	North America	Special Purpose
	Firefly Scoot seat - Leckey [22]	2014	Designer	Ireland	Customisable or Modular
	Upsee Walking with adult support harness [23]	2014	Designer/Parent	Israel	Special Purpose
	Piccolino power chair - Paravan [24]	2016	Engineer	Germany	Special Purpose

	CONTRIBUTION NAME	2016	Designer/Engineer	North America	Special Purpose
	TrexoPlus exoskeleton gait trainer -Trexo Robotics [25]	2016	Designer/Engineer	North America	Special Purpose
	Atlas2030 exoskeleton - Marsi Care & CSIC [26]	2016	Designer/Engineer	Spain	Special Purpose

Table 6. Interventional Contributions (I.2) which remained as concepts or prototypes.

MQ1 - **I.2**

	CONTRIBUTION NAME	MQ2 YEAR	MQ3 CONTRIBUTOR	MQ4 GEOGRAPHY	MQ5 DESIGN APPROACH
2000s	Hanna's Upright powered walker [27]	1986-1995	Engineer/Parent	Sweden	Special Purpose
	UD1 Robot - University of Delaware [28]	2007-2007	Design Student	North America	Special Purpose
	A2B Tricycle - Hadassa College [29]	2008-2008	Design Student	Israel	Customisable or Modular
	CPLEGIA - Mimar Sinan Fine Art University [30]	2009-2009	Design Student	Turkey	Special Purpose
	UD2 - University of Delaware [31]	2009-2011	Engineering Student	North America	Special Purpose
2010s	Ugo supportive wheeled seat Aalborg University [32]	2010-2010	Design Student	Denmark	Customisable or Modular
	WeeBot - Ithaca College [33]	2011-2011	Healthcare	North America	Special Purpose
	Chair 4 Life power chair - Renfrew [34]	2012-2014	Design Consultancy	UK	Special Purpose
	The Play & Mobility Device - Grand Valley State University [35]	2015-2015	Engineering student	North America	Special Purpose
	Evolvable Walking Aid Brunel University London [36]	2015-2017	Design Student	UK, Peru	Special Purpose

Table 7. Theoretical Contributions (T).

MQ1 - **T**

	CONTRIBUTION NAME	MQ2 YEAR	MQ3 CONTRIBUTOR	MQ4 GEOGRAPHY	MQ5 DESIGN APPROACH
1970s	The Chronically Sick and Disabled Persons Act, the first in the world to give rights to people with disabilities. [37]	1970	Policymakers	UK	User Aware

	Section 504 of the Rehabilitation Act - Prohibits discrimination and exclusion based on physical barriers. [38]	1973	Policymakers	North America	User Aware
	Education for all Handicapped Children Act (EHA) guarantees free education and supports services to enact it. [39]	1975	Policymakers	North America	Customisable or Modular
1980s	Social Model of Disability [40]	1980	Healthcare	Globally	User Aware
	The UN designates 'The International Year of Disabled People' [41]	1981	Policymakers	Globally	Customisable or Modular
	Education Act laid down that children should be educated in mainstream schools or classes wherever possible [42]	1981	Policymakers	UK	User Aware
	The Assistive Technology Act mandates the right to appropriate IPM devices [43]	1988	Policymakers	North America	Special Purpose
	The Children Act, section 17 to provide advice, services and support to children with disabilities [44]	1989	Policymakers	UK	User Aware
1990s	Inclusive Design Principles [45]	1990	Designer	UK	User Aware
	Disability living Allowance is introduced [46]	1992	Policymakers	UK	Customisable or Modular
	Reauthorization of the 1988 Tech Act to improve access to AT devices [47]	1998	Policymakers	North America	Special Purpose
2000s	Improving Access to AT for Individuals with Disabilities Act provides *legal* right to AT from birth to death [48]	2004	Policymakers	North America	Special Purpose
	Childhood Mobility Design Principles - Dragon Mobility [49]	2004	Designer/ Engineer	UK	Customisable or Modular
	Inclusive Healthcare Product Design Principles - F. Nickpour, C.O'Sullivan [50]	2016	Designer	UK	Customisable or Modular

Table 8. Methodological Contributions (M).

MQ1 - **M**

CONTRIBUTION NAME	MQ2 YEAR	MQ3 CONTRIBUTOR	MQ4 GEOGRAPHY	MQ5 DESIGN APPROACH
Human-centred Design Process [51]	1980	Designer	North America	User Aware
Inclusive Design Process [52]	1990	Designer	UK	User Aware
Double Diamond Design process - Design Council [53]	2005	Designer	UK	User Aware
MSc in Disability, Design and Innovation (processes and techniques) - GDI Hub [54]	2019	Designer	UK	Customisable or Modular

Table 9. Empirical Contributions (E).

MQ1 - **E**

CONTRIBUTION NAME & BRIEF DESCRIPTION	MQ2 YEAR	MQ3 CONTRIBUTOR	MQ4 GEOGRAPHY	MQ5 DESIGN APPROACH
Parent/Caregiver Perspectives on power wheelchair [55]	1996	Healthcare	North America	N/A
A wheelchair can be fun: a case of emotion-driven design [56]	2003	Design	Netherlands	Customisable or Modular
Practice considerations for the introduction and use of power mobility for children [57]	2013	Healthcare	North America	N/A
Power mobility for children: a survey study of American and Canadian therapists' perspectives and practices [58]	2018	Healthcare	North America	N/A
Children's, Parents', and Occupational Therapists' Perceptions of Powered Mobility [59]	2018	Healthcare	North America	N/A
Participatory photovoice narrative study exploring powered mobility provision for children and families [60]	2018	Healthcare	North America	N/A
Impacts of early powered mobility provision on disability identity case study [61]	2018	Healthcare	North America	N/A

5.2 Illustrative Mapping of Data

The data collection results were translated into a visual map (Figure 2) to illustrate designerly contributions to the field of IPM between 1970 and 2020, based on type of contribution and contributors' stakeholder group(s).
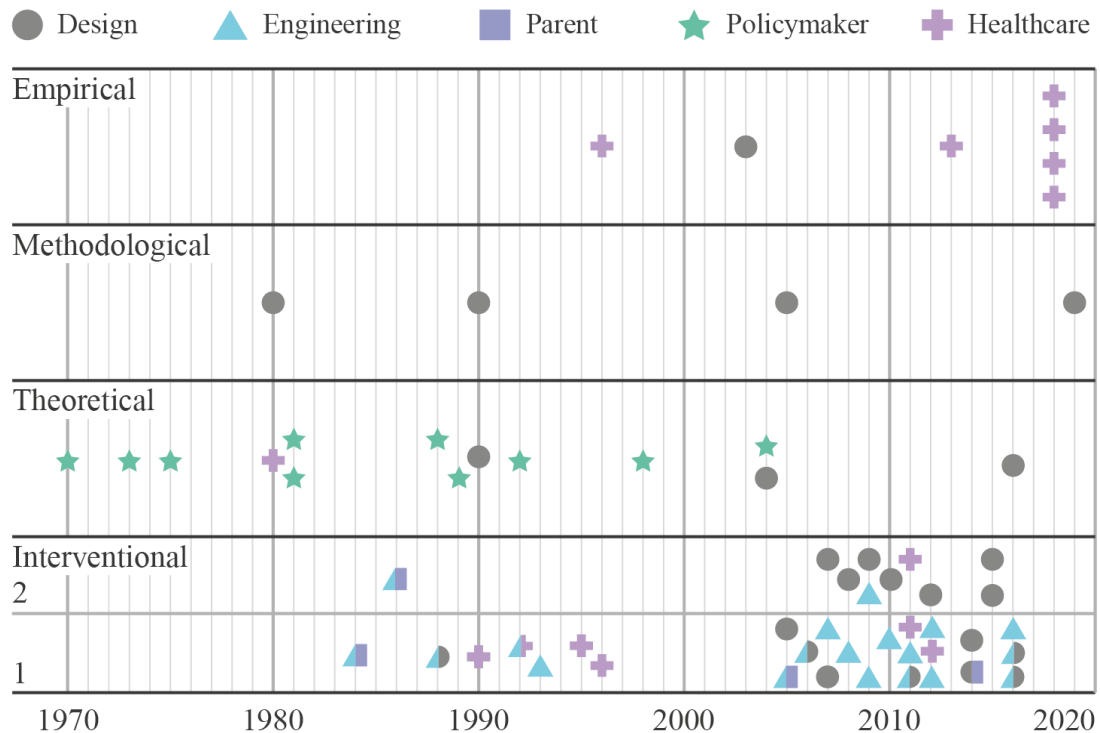

Figure 2. Illustrative map of designerly contributions in IPM between 1970 and 2020, based on type of contribution and contributor's stakeholder group(s).

5.3 Key Findings

In total, 1417 results were found in the electronic database searches, of which 503 duplicates were removed. After screening titles and abstracts, 76 of the 914 contributions remained. The authors independently screened full-texts to determine if they met all inclusion criteria, after which a further 20 were excluded. In total, 56 results were deemed eligible for inclusion from electronic database searches. The initial findings were shared with a total of eight experts for review and input. Accordingly, a further five contributions were included, bringing the total number of contributions deemed eligible for inclusion to 61. Of these, 36 were classified as interventional, 14 were classified as theoretical, four were classified as methodological, and seven were classified as empirical. Top reasons for excluding contributions were: focus on adult mobility only, focus on passive mobility only, interventional designs with no evidence of intention to commercialise or implement, contributions lack novelty and classed as 'copycat', or contributions which demonstrate only incremental updates or improvements to existing contributions. Key findings about the context and nature of contributions, and their collective significance in the landscape of IPM, are discussed under the two themes of chronology and typology.

CHRONOLOGY. Following the shift in narratives of mobility rehabilitation in the late 1970s from 'normalising' to 'optimising' mobility (Butler, 2009), interventional IPM contributions begin to emerge in the form of beginner paediatric power chairs [1][4][5][6][7]. This continues to be the most prominent type of IPM design contribution until 2020. This is later accompanied by empirical contributions in the form of therapist-led studies mentioning design features and/or stakeholder perspectives [55][56][57], which appears to reflect a realisation of the benefits, and thus urgency, to build a case around providing better designed IPM at the earliest possible age.

TYPOLOGY. The majority of the recorded contributions came from North America, the United Kingdom, and Scandinavia. Of the 36 recorded interventional design contributions, 26 reached commercialisation and 10 remained at concept or prototype stage. Of the 26 that reached commercialisation, at least 6 were discontinued in less than 15 years. Seven out of the 10 interventional contributions which remained as concepts, were created by design or engineering university students with limited industry experience. Although many of the interventional contributions involved stakeholders from other disciplines throughout the design process, the majority were led by stakeholders from Design or Engineering disciplines, with the exception of four contributions led by Occupational Therapists, one led by a Kinesiologist, and one founded by a philanthropist. None of the interventional contributions were approached with the definition of 'user aware approach' (see section 2.1), whilst seven were approached with a 'modular/customisable approach' and the remaining 29 were designed with a 'specialist assistive approach'. Of the 36 interventional contributions, 21 were designs of power chairs, 7 were walking aids or exoskeletons, and 8 were other products e.g. self-powered mobility devices and pieces of technology. The strongest trend across all classification types is the steady increase in the number of new contributions per decade since the 1970's, and a spike in contributions in the 2010's.

6. Discussion

6.1 Learning from History and Questioning the Present

Contributions captured by the mapping review were investigated by gathering background information about them, including their year of creation, geographic location, discipline of contributors and design approach. All contributions captured by the mapping review were then further analysed by investigating the contributor's experience, motivations, methodologies, narratives, and terminology used. Analysing the map in this way enabled the data to grow into a story about the history of IPM design, and helped to identify a number of key insights which have been summarised and discussed under the following five themes.

DOCUMENTATION & REPRESENTATION. The review revealed a somewhat disjointed and heavily unbalanced landscape of IPM design efforts. Moreover, these efforts were poorly recorded, making it difficult to locate and capture grey literature and unpublished fieldwork or artefacts, especially for discontinued interventional contributions. In most cases, once located, the documentation itself was not thorough and rigorous. A total lack of theoretical,

methodological, or empirical contributions relating specifically to the process of designing IPM interventions, may reflect knowledge-sharing barriers (Riege, 2005) or an 'end-result-oriented' mentality; considering only certain polished aspects of a final solution valuable or worthy of being recorded, communicated, and represented (Wong & Radcliffe, 2000).

Short-term measures such as aspirational design awards and media coverage (mainly under narratives of invention or innovation) are represented as indicators of success (Norman, 2010) and were the threads of grey literature which uncovered many of the I.2 interventional contributions. These are mainly focused on well-presented inspirational prototypes, videos, or illustrations of final products. At the same time, design processes, failures, long-term measures of success and empirical knowledge are typically kept in-house, if documented at all, and as a result have little or no representation. Adding to this, the overall representation of empirical contributions appears skewed towards stakeholders with an academic background, with all of them being published by therapists or designers affiliated with an academic institution and/or holding a postgraduate degree. This is likely due to documentation and dissemination of knowledge being encouraged and allocated more time in academic settings in comparison to industry.

DESIGN APPROACH & KNOWLEDGE. One prominent gap in the field of IPM design is the lack of contributions taking a 'user-aware' design approach. Instead, the majority of contributions employ a 'special purpose' design approach to create 'assistive technology' (Newell, 2003), which tends to be targeted at smaller markets and typically results in higher costs. Funding issues are reported as a major barrier to acquisition through private purchasing or satisfying health service commissioning budgets, and has wider health economics implications (Guerette et al., 2005).

Apart from one contribution in 2004, relating to design principles specifically for IPM [49], there remains a total lack of contributions relating to frameworks, processes, or methods relating to the IPM design process. The limited number of theoretical and methodological contributions, specific to the IPM field, leaves little foundation for new interventional contributions to learn from and build upon. This also means there are no rigorous principles or measures to assess quality, steer and define success in IPM design. Hence, the short-term spotlight approach to defining and measuring success.

Literature around new developments in exoskeleton technologies for children has grown increasingly throughout the 2010s yet only 2 interventional records [25][26] are captured. This could reflect the timely process of pushing a new product through to market, or it could be seen as an experimental and exploratory time of future-thinking; a habitual characteristic of designers.

STAKEHOLDER COLLABORATION & INTERDISCIPLINARITY. A pattern in the development of interventional contributions is that they have been mainly led by an individual or small team of engineers and/or designers. Most collaborated with occupational therapists and parents at some point during the definition and delivery stage. However, there is little evidence or trend of continued involvement from other disciplines or stakeholders throughout the

process. It is worth noting that a few of the interventional contributions were developed by designers/engineers who also had lived experience of another stakeholder group (e.g. also being a parent to a child with mobility disability). Only six interventional contributions were recorded where research and development was *led* by someone with a healthcare related background [3][6][7][18][20][33].

A number of empirical contributions involved children, parents and therapists, but limited overlap is seen between stakeholders in the IPM design process. This suggests that multidisciplinary and co-design approaches to interventional contributions have either not been adopted, or are simply not recorded. Either way, it is clear that no contribution to the field of IPM design has taken a holistic approach to involve all key stakeholders, and potentially beneficial expert disciplines. Doing this could bring new perspectives and narratives to the field, stimulating and altering the way interventions are imagined, and subsequently designed.

Currently, designers and engineers appear to get the final say on which features are appropriate and significant enough to be included or excluded in an intervention, but evidence shows that therapists and parents are not always satisfied with this (Livingstone & Paleg, 2014). It is important to acknowledge and balance healthy tensions in terms of narratives and requirements across disciplines and set a transdisciplinary criteria for IPM progress in order to encourage stakeholders to step out of their silos and start collaborating more closely together. It is essential to look beyond the field of IPM to better consider, involve, and understand current thinking in broader subject spheres such as childhood, disability and mobility, as well as involve the stakeholders and disciplines currently excluded. This could be facilitated through a values and requirements framework (Harries et al., 2015) and would require a transdisciplinary, co-creative and child-centred approach. It could be argued that the recorded methodological contributions do not belong specifically to the field of IPM design, but rather to the broader discipline of design, despite the direct influence they have on the field. This raises the question: what have we been missing from within the other overarching disciplines that make up IPM design?

GEOGRAPHICS & REGIONALITY. There is a significant lack of novel IPM design contributions recorded from developing regions of the world. This could be due to limitations of the search strategy, poor documentation of possible contributions, or general lack of contributions to the field of IPM from these regions. Whatever the case, there remains insufficient data available to gain reliable understanding of IPM design in developing contexts. Focusing the scope of further research on developing regions of the world, could be one future direction. Using design principles to redesign or adapt interventions is one way to extend the reach of IPM design to also suit developing regions of the world (Nickpour and O'Sullivan, 2016).

The rise of IPM design contributions in developing countries is predicted to accelerate in the coming decade as research and policy push to enforce access to IPM as a human right. This is echoed by the introduction of new organisations and programmes steered towards the design of interventions for such regions, more sustainable and local infrastructure around design and development, and more affordable and inclusive technologies (AT2030 Programme, 2019).

OPERATIONAL & MARKET CHARACTERISTICS. A primary consideration in the development of IPM interventions is the way in which they will achieve impact; this appears to vary based on the contributor's position on a spectrum of identified operational profiles. On one end of the spectrum exist projects which are instigated by those with a vested personal interest or social and corporate responsibility, such as third sector charities and family members. These are typically small-scale organisations, cottage industries, or start-ups which lack budget, investment, and a clearly defined business strategy from the outset. On the other end of the spectrum, there are large-scale commercial organisations who already mass-manufacture adult mobility equipment and have well established routes to market. The former is an agile entity with the ability to adapt and change designs as and when needed to allow for greater impact for individuals, but struggles with economies of scale and financial sustainability; some tend to involve a social aspect in their business model such as a subsidised loan schemes (Wizzybug Loan Scheme, 2011; Bugzi Loan Scheme, 2013). The latter is able to achieve greater impact through reaching larger markets, hence more end-users. However, they are profit-driven and thus can be slow to introduce new products unless financially motivated; they struggle most with desirability and affordability issues.

There also appears to be a disparity between design application and successful intervention, where a considerable number of interventional concepts or prototypes, never make it to being used or commercialised. This could reflect on a myriad of issues with navigating complex and highly regulated healthcare systems, inadequate manufacturing plans, or lack of commercialisation or commissioning strategy from the outset of a project. It could also reflect sparse project funding opportunities and investment activity in the IPM sector. It would be interesting to closely examine the relationship between the short and long term success of IPM interventions in relation to viability, feasibility, and desirability, and how their features address the hierarchy of user experience (Anderson, 2011). Equally, it would be interesting to investigate the reason for IPM interventions being discontinued having reached the market, to answer if this relates to the nature of the market or to the quality of the interventions.

6.2 Towards a Design Framework for the Future of IPM

The mapping review rendered the field of IPM design as currently lacking a holistic and rigorous reference point to define, measure, assess and improve the value and impact of contributions. Thus, distinguishing between change and progress becomes difficult, and there is little scope to help facilitate future contributions. Incorporating this into a design framework for IPM will enable progress to be monitored and help move towards a well-defined, ideal situation in IPM design. Mapping past and present contributions helped uncover some major gaps and insights in the IPM design field and highlighted the possibility for paradigm shifts to take place on the level of product, service, and system design. Shifting from the traditional limited choice of designs to fully customisable designs, from rigid functionality to adaptable smart technology, from purchasing a mobility product to purchasing mobility as a service, or from niche to mass markets. Practical considerations to help visualise and steer the future of IPM design have been outlined in table 10, to be embodied through the development of an IPM design framework which ultimately intends to optimise the experience of childhood.

Table 10. Considerations for the future of IPM design.

Documentation & Representation	● Consider IPM impact measurement criteria from the outset, to build in means of evidencing long-term results or benefits of interventions.
	● Record and share theoretical and methodological contributions from Designers and Engineers as well as just 'end product' interventional contributions.
	● Reflect on and document failed or discontinued interventional contributions.
Design Approach & Knowledge	● Identify the narrative being used before starting the design process. Question how alternative narratives could reframe the design goal and design approach.
	● Take a radical product-service system (PSS) innovation approach to IPM design to move beyond incremental changes.
	● Adopt a user-aware approach in the design of your IPM interventions where possible.
	● Consider commercial viability, business strategy and sustainability before developing concepts.
Stakeholder collaboration & Interdisciplinarity	● Make the documentation and circulation of Designers' and Engineers' empirical and tacit knowledge part of the design process.
	● Give IPM healthcare stakeholders and end-users a major role in the development of interventional contributions.
	● Use design principles and frameworks to assist with decision making in interdisciplinary teams with conflicting opinions or requirements.
	● Capture not only knowledge and requirements, but also higher level narratives and principles across contributing disciplines and stakeholders.
	● Build transdisciplinarity into the design process through: exploring foundational and ancillary IPM subject areas, acknowledging their complex and sometimes conflicting narratives and requirements, and capturing the diversity across disciplines and stakeholders.
Geographics & Regionality	● Support global development of IPM interventions through knowledge sharing and making designs open source.
	● Consider what it would take to make IPM interventions for developed regions of the world suitable and appropriate also for developing regions of the world, and if these choices and justifications can be embodied by design principles.
Operational & Market Characteristics	● Small organisations should consider and define their route to market early on, and calculate the budget runway required to get there.
	● Large established organisations should encourage exploration and development of new ideas based on emerging IPM needs and/or wants.
	● IPM healthcare stakeholders should conduct larger scale empirical case studies to better reflect and measure impact of interventions.
	● IPM designers should focus efforts on the development of novel mobility interventions rather than incremental changes to power wheelchairs.

7. Conclusion and Future Research Direction

This study reviewed 61 contributions to the field of IPM design between 1970 and 2020. Design contributions were classified and discussed under Theoretical, Methodological, Empirical, and Interventional categories. The review synthesises the evolution of the IPM design field, showing how it has progressively grown from a technical and low volume product-centric cottage industry, towards a larger scale commercialised industry producing IPM interventions without fully considering social, economic, environmental, political and legal states.

Key insights from the mapping review are categorised into five themes: Documentation and Representation, Design Approach and Knowledge, Collaboration and Interdisciplinarity, Geographics and Regionality, and Operational and Market Characteristics. A table of considerations for future IPM design outlines initial suggestions going forward. These will inform a framework for future IPM designs to help steer, improve, and facilitate future product and service interventions.

Further research is needed to enhance thoroughness of the mapping review and to further investigate and analyse the identified contributions and themes. In parallel, real-world observation of an IPM design project from the outset, as well as capturing IPM stakeholders' narratives and requirements, would establish research triangulation needed for outlining the IPM design framework.

8. References

Anderson, S. (2011). User Experience Hierarchy. *Seductive Interaction Design: Creating Playful, Fun, and Effective User Experiences.* New Riders Publishing, Berkeley CA.

AT2030 Programme (2019). Available: https://at2030.org/objectives/ [Dec 01, 2019].

Bray, N., Noyes, J., Harris, N. and Edwards, R.T. (2017). Defining Health-related Quality of Life for Young Wheelchair Users: A Qualitative Health Economics Study. Plos One, 12(6).

Brown, T. and Jernigan, T. (2012). Brain Development during the Preschool Years. Neuropsychology Review, 22(4), Pp. 313-333.

Bugzi Loan Scheme (2013). Queen Elizabeth Foundation for Disabled People. Available: https://qef.org.uk/our-services/qef-mobility-services/bugzi-loan-scheme [Nov 25, 2019].

Butler, C (2009). Effective Mobility for Children with Motor Disabilities.

Casey, J., Paleg, G. and Livingstone, R. (2013). Facilitating Child Participation through Power Mobility. British Journal of Occupational Therapy, 76(3), Pp. 158-160.

Casey, J., Paleg, G., Livingstone, R. and Rodby-Bousquet, E. (2015). Providing Power and Mobility to Toddlers around the World.

Clarkson, J., Coleman, R (2015). History of Inclusive Design in the UK. Applied Ergonomics, 46(B), Pp. 235-247

Desmet P. and Dijkhuis, E. (2003). A Wheelchair Can Be Fun: A Case of Emotion-driven Design. Designing Pleasurable Products and Interfaces 2003, Pp 22–27.

Durkin, J. (2002). The Need for the Development of a Child Led Assessment Tool for Powered Mobility Users. Technology and Disability, 14(4), Pp. 163-171.

Feldner, Logan, and Galloway (2016). Why The Time Is Right For A Radical Paradigm Shift In Early Powered Mobility: The Role Of Powered Mobility Technology Devices, Policy And Stakeholders. Disability and Rehabilitation: Assistive Technology, 11(2), Pp. 89-102.

Field, D. (1999). Powered Mobility: A Literature Review Illustrating the Importance of a Multifaceted Approach. Assistive Technology, 11(1), Pp. 20-33.

Global Disability Innovation Hub (2019). MSc Disability, Design and Innovation at UCL. Available: https://www.disabilityinnovation.com/education/msc-ddi [Dec 8, 2019].

Google Impact Challenge (2015). The Google Impact Challenge: Disabilities. Available: https://www.google.org/impactchallenge/disabilities/about.html [Dec 14, 2019].

Grant, M., and Booth, A. (2009). A Typology of Reviews: An Analysis of 14 Review Types and Associated Methodologies. Health Information & Libraries Journal, 26(2), Pp. 91-108.

Guerette, P., Furumasu, J. and Tefft, D. (2013). The Positive Effects of Early Powered Mobility on Children's Psychosocial and Play Skills. Assistive Technology, 25(1), Pp. 39-48.

Guerette, P., Tefft, D. and Furumasu, J., (2005). Pediatric Powered Wheelchairs: Results of a National Survey of Providers. Assistive Technology, 17(2), Pp. 144-158.

Harries, P.A., Giacomin, J., Nickpour, F., Young, W., Unsworth, C. and Boniface, G. (2015). Scoping Our Future Research Priorities. Motability Report.

Jahan, N., Naveed, S., Zeshan, M. and Tahir, M. (2016) How To Conduct A Systematic Review: A Narrative Literature Review.

Kenyon, L.K., Jones, M., Livingstone, R., Breaux, B., Tsotsoros, J. and Williams, K.M. (2018). Power Mobility for Children: A Survey Study of American and Canadian Therapists' Perspectives and Practices. Developmental Medicine & Child Neurology, 60(10), Pp. 1018-1025.

Leaman, J. and La, H.M. (2017). A Comprehensive Review of Smart Wheelchairs: Past, Present and Future.

Lim, Y., Nickpour, F., Giacomin, J. (2016) Beyond Accessible Mobility: Insights into Psychosocial Inclusivity Dimensions in Personal Transport.

Livingstone, R. (2010)**.** A Critical Review of Powered Mobility Assessment and Training for Children.

Disability & Rehabilitation: Assistive Technology, 5(6), Pp. 392-400.

Livingstone, R. and Paleg, G. (2014). Practice Considerations for the Introduction and Use of Power Mobility for Children. Developmental Medicine & Child Neurology, 56(3), Pp. 210-221.

Logan, S.W., Feldner, H.A., Bogart, K.R., Goodwin, B., Ross, S.M., Catena, M.A., Whitesell, A.A., Sefton, Z.J., Smart, W.D. and Galloway, J.C., (2017). Toy-based Technologies for Children with Disabilities Simultaneously Supporting Self-directed Mobility, Participation, and Function: A Tech Report. Frontiers in Robotics and AI.

Lunsford, C., Grindle, G., Salatin, B. and Dicianno, B. (2016). Innovations With 3-dimensional Printing in Physical Medicine and Rehabilitation: A Review of the Literature. Pm&R, 8(12), Pp. 1201-1212.

Manero, A., Smith, P., Sparkman, J., Dombrowski, M., Courbin, D., Kester, A., Womack, I. and Chi, A. (2019). Implementation of 3D Printing Technology in the Field Of Prosthetics: Past, Present, and Future. International Journal of Environmental Research and Public Health, 16(9).

Miake-Lye, I., Hempel, S., Shanman, R. and Shekelle, P. (2016). What Is An Evidence Map? A Systematic Review of Published Evidence Maps and Their Definitions, Methods, and Products. Systematic Reviews, 5, Pp. 28.

Nayak, S., Chavan, N. and Srinath, N., (2016). User Centered Inclusive Design For Assistive Technology, Dec 2016, Ieee, Pp. 1-6.

Nesta, (2014). Inclusive Technology Prize. Available: https://www.nesta.org.uk/project/inclusive-technology-prize/

Newell, A. and Gregor, P. (1997). Chapter 35 - Human Computer Interfaces For People With Disabilities. In: M.G. Helander, T.K. Landauer and P.V. Prabhu, Eds, Handbook of Human-computer Interaction (Second Edition). Amsterdam: North-holland, Pp. 813-824.

Newell, A. (2003). Inclusive Design or Assistive Technology. In: P.J. Clarkson, R. Coleman, S. Keates and C. Lebbon, Eds, Inclusive Design: Design for the Whole Population. London: Springer-verlag, Pp. 172-181.

Nickpour, F. and O'Sullivan, C. (2016) Designing an Innovative Walking Aid Kit; A Case Study of Design in Inclusive Healthcare Products. In: Langdon P., Lazar J., Heylighen A., Dong H. (eds) Designing Around People. Springer, Cham.

Nilsson, L., Eklund, M., Nyberg, P. and Thulesius, H., (2011). Driving To Learn In a Powered Wheelchair: The Process of Learning Joystick Use in People with Profound Cognitive Disabilities. American Journal of Occupational Therapy, 65(6), Pp. 652-660.

Norman, D. (2010). Why Design Contests Are Bad: https://www.core77.com/posts/17024/Why-Design-Contests-Are-Bad [Dec 15, 2019].

O'Sullivan, C., and Nickpour, F. (2020). Drivers for Change; Initial Insights from Mapping Half a Century of Inclusive Paediatric Mobility Design. AHFE 2020.

Pituch, E., Rushton, P.W., Ngo, M., Heales, J. and Poulin Arguin, A. (2018). Powerful or Powerless? Children's, Parents', And Occupational Therapists' Perceptions of Powered Mobility. Physical & Occupational Therapy in Pediatrics, 0(0), Pp. 1-16.

Riege, A. (2005). Three-dozen Knowledge-sharing Barriers Managers Must Consider. Knowledge Management, 9, Pp. 18-35.

Rosen, L., Plummer, T., Sabet, A., Lange, M.L. And Livingstone, R. (2017). Resna Position on the Application of Power Mobility Devices for Pediatric Users. Assistive Technology, 0(0), Pp. 1-9.

Rushton, P.W., Kairy, D., Archambault, P., Pituch, E., Torkia, C., El Fathi, A., Stone, P., Routhier, F., Forget, R., Pineau, J., Gourdeau, R. and Demers, L. (2015). The Potential Impact of Intelligent Power Wheelchair Use on Social Participation: Perspectives of Users, Caregivers and Clinicians. Disability and Rehabilitation: Assistive Technology, 10(3), Pp. 191-197.

Soh, H. and Demiris, Y. (2012). Towards Early Mobility Independence: An Intelligent Paediatric Wheelchair with Case Studies.

Thorsen, R., Bortot, F. and Caracciolo, A. (2019). From Patient To Maker - A Case Study Of Co-designing An Assistive Device Using 3D Printing. Assistive Technology, 0(0), Pp. 1-7.

Toyota Mobility Foundation, (2018). Toyota Mobility Unlimited Challenge. Available: https://mobilityunlimited.org/challenge [Dec 14, 2019].

Turner, A., Liddy, E., Bradley, J. and Wheatley, J. (2005). Modelling Public Health Interventions for Improved Access to the Grey Literature. Journal of the Medical Library Association: JMLA, 93(4), Pp. 487-494.

Wiart, L. and Darrah, J. (2009). Changing Philosophical Perspectives On The Management Of Children With Physical Disabilities--their Effect On The Use Of Powered Mobility. Disability and Rehabilitation.

Wizzybug Loan Scheme. (2011) Designability. Available: https://designability.org.uk/meet-wizzybug/about-the-loan-scheme/ [Nov 25, 2019].

Wobbrock J. (2016). Research Contribution Types In Human-computer Interaction.

Wong, W. and Radcliffe, D. (2000). The Tacit Nature of Design Knowledge. Technology Analysis & Strategic Management, 12(4), Pp. 493-512.

9. Appendix A

This appendix provides references exclusively for the contributions listed in tables 5, 6, 7, 8, and 9. Unlike the rest of the paper, a numerical referencing style has been adopted here, to make it easier to find and look up each contribution in the order they are listed in the tables.

[1] The Turbo/BobcatDX. Everaids Ltd. http://daneverard.co.uk/mobility/history.php - [Accessed 04/11/19]

[2] Aug-mentative mobility aid Smart Wheelchair. CALL Centre. https://www.callscotland.org.uk/information/smart-wheelchair/ - [Accessed 04/11/19]

[3] Mobility equipment charity. WhizzKidz. http://www.whizz-kidz.org.uk/support-us/the-difference-you-make/the-story-so-far - [Accessed 04/11/19]

[4] The CooperCar. RJ Cooper & Associates. Inc. https://ieeexplore.ieee.org/document/217385 - [Accessed 04/11/19]

[5] BIME Infant and Junior Bugs. Designability. https://designability.org.uk/meet-wizzybug/history-of-wizzybug/ [Accessed 04/11/19]

[6] Gobot. Wright, C. (1999). The Gobot: A Transitional Powered Mobility Aid for Young Children with Physical Disabilities

[7] Tiro (C300). Lisbeth Nilsson and Permobil. http://www.lisbethnilsson.se/en/tiro-the-learning-tool/ - [Accessed 04/11/19]

[8] Bugzi. Medical Engineering Resource Unit, QEF. https://meru.org.uk/product/bugzi-powered-wheelchair-for-children/ - [Accessed 04/11/19]

[9] Dragon power chair. Dragon Mobility. http://dragonmobility.com/ACPOCpaper.html - [Accessed 04/11/19]

[10] Permobil Koala. Permobil. https://permobilus.com/wp-content/uploads/2016/12/SM-Koala.pdf - [Accessed 04/11/19]

[11] Wizzy Bug. Designability. https://designability.org.uk/meet-wizzybug/ - [Accessed 04/11/19]

[12] Balder Junior power chair. Etac.
https://www.etac.com/c4documents/rev.5,%2006.06.2007_552244.pdf - [Accessed 04/11/19]

[13] Zippie Salsa M2 mini. Sunrise Medical. https://www.activemobility.co.uk/download/10146.pdf -
[Accessed 04/11/19]

[14] Skippi. Ottobock. https://www.ottobock.co.uk/wheelchairs-seating/kids/powered/skippi/ -
[Accessed 04/11/19]

[15] Self-initiated prone progressive crawler - Virginia Commonwealth University -
https://patents.google.com/patent/US8942874B2/en - [Accessed 04/11/19]

[16] TinyTrax -Imaginable Ltd - https://www.tinytrax.com/ - [Accessed 04/11/19]

[17] Drive Deck wheelchair platform - Smile Smart Technology - https://www.smilesmart-
tech.com/assistive-technology-products/drivedeck/ - [Accessed 04/11/19]

[18] AKKA Mobility Platform - Jonasson, M. (2013). The AKKA-board - Performing Mobility, Disability
and Innovation.

[19] Systems Collision Avoidance Device (SCAD). Chailey Heritage.
https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=14511 - [Accessed 04/11/19]

[20] Go-Baby-Go toy car adaption Service. University Of Delaware. https://sites.udel.edu/gobabygo/
- [Accessed 04/11/19]

[21] Spectra Blitz. Invacare. https://www.invacare.eu.com/spectra-blitz-ma-93speblen - [Accessed
04/11/19]

[22] Firefly Scoot. Leckey. https://www.leckey.com/products/firefly-scooot - [Accessed 04/11/19]

[23] Upsee walking with adult support harness. Leckey. https://www.fireflyfriends.com/upsee -
[Accessed 04/11/19]

[24] Piccolino. Paravan. http://www.precisionrehab.co.uk/products/paravan-products/piccolino/ -
[Accessed 04/11/19]

[25] TrexoPlus exoskeleton gait trainer. Trexo Robotics. https://trexorobotics.com/our-story/ -
[Accessed 04/11/19]

[26] Atlas2030 exoskeleton. Marsi Care & CSIC. https://www.marsibionics.com/atlas-pediatric-exo-
pacientes/ - [Accessed 04/11/19]

[27] Hanna's Upright powered walker. Flodin, E. (2007) Interactive Design. The Desire for
Autonomous Upright Mobility: A Longitudinal Case Study. Technology and Disability, vol. 19, no. 4,
pp. 213-224.

[28] UD1 Robot. University of Delaware.
http://www1.udel.edu/research/media/babiesrobotsgallery.html - [Accessed 06/11/19]

[29] A2B Tricycle. Hadassa College. https://www.behance.net/gallery/6885451/A2B-Tricycle-for-
Disabled-%282008%29 - [Accessed 06/11/19]

[30] CPLEGIA. Mimar Sinan Fine Art University. https://www.coroflot.com/ozlemkok/CPLEGIA -
[Accessed 06/11/19]

[31] UD2 - Ragonesi, C., Chen, x., Agrawal, S., Galloway, J, C. (2010) Power Mobility and Socialization in Preschool: A Case Study of a Child with Cerebral Palsy.

[32] Ugo supportive wheeled seat. Aalborg University. https://projekter.aau.dk/projekter/en/studentthesis/ugo(c848760b-78f9-4f51-ad09-14f58789f652).html - [Accessed 06/11/19]

[33] WeeBot. Dennis, C., Stansfield, S. (2011) TheWeeBot: Feasibility of a Mobility Option for Infants.

[34] Chair 4 Life. Renfrew. https://www.renfrewgroup.com/portfolio/chair-4-life/ - [Accessed 06/11/19]

[35] Play & Mobility Device. Grand Valley State University. https://www.gvsu.edu/gvnext/2015/gvsu-students-build-mobile-device-for-child-with-6645.00000.htm - [Accessed 06/11/19]

[36] Evolvable Walking Aid. Brunel University London. https://www.designindaba.com/videos/creative-work/adaptable-walking-aid-costs-less-70-pence-build - [Accessed 06/11/19]

[37] The Chronically Sick and Disabled Persons Act, the first in the world to give rights to people with disabilities. http://www.legislation.gov.uk/ukpga/1970/44 - [Accessed 07/11/19]

[38] Section 504 of the Rehabilitation Act - Prohibits discrimination and exclusion based on physical barriers. https://dredf.org/legal-advocacy/laws/section-504-of-the-rehabilitation-act-of-1973/ - [Accessed 07/11/19]

[39] Education for all Handicapped Children Act (EHA) guarantees free education and supports services to enact it. https://www2.ed.gov/policy/speced/leg/idea/history.html - [Accessed 07/11/19]

[40] Social Model of Disability - Beyond (Models of) Disability - JS. Beaudry - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4886464/ - [Accessed 08/11/19]

[41] The UN designates The International Year of Disabled People - https://www.un.org/development /desa/disabilities/the-international-year-of-disabled-persons-1981.html - [Accessed 08/11/19]

[42] Education Act laid down that children should be educated in mainstream schools or classes wherever possible - http://www.open.ac.uk/health-and-social-care/research/shld/timeline-learning-disability-history - [Accessed 08/11/19]

[43] The Assistive Technology Act mandates the right to appropriate IPM devices https://www.congress.gov/bill/105th-congress/senate-bill/2432 - [Accessed 08/11/19]

[44] The Children Act, section 17 to provide advice, services and support to children with disabilities and their families - http://www.legislation.gov.uk/ukpga/1989/41/section/17 - [Accessed 08/11/19]

[45] Inclusive Design Principles - IHCD - https://www.humancentereddesign.org/inclusive-design/principles - [Accessed 08/11/19]

[46] Disability living Allowance is introduced - https://publications.parliament.uk/pa/cm199798/cmselect/cmsocsec/641/64104.htm - [Accessed 08/11/19]

[47] Reauthorization of the 1988 Tech Act to improve access to AT devices - Scherer, M. J, (2011) Assistive Technologies and Other Supports for People with Brain Impairment. Page 216. Springer Publishing Company.

[48] Improving Access to AT for Individuals with Disabilities Act provides legal right to AT from birth to death https://files.eric.ed.gov/fulltext/EJ842007.pdf - [Accessed 08/11/19]

[49] Childhood Mobility Design Principles - D. Everard - http://daneverard.co.uk/mobility/principles.php - [Accessed 08/11/19]

[50] Inclusive Healthcare Design Principles - F. Nickpour, C.O'Sullivan - https://link.springer.com/chapter/10.1007/978-3-319-29498-8_5 - [Accessed 08/11/19]

[51] Human-centred Design Process - E.Friess - Design Issues, V26, Issue 3 - https://www.mitpressjournals.org/doi/10.1162/DESI_a_00028 - [Accessed 11/11/19]

[52] Inclusive Design Process - History of Inclusive Design in the UK, J.Clarkson R.Coleman - https://www.sciencedirect.com/science/article/abs/pii/S0003687013000410?via%3Dihub - [Accessed 11/11/19]

[53] Double Diamond Design process - Design Council - https://www.designcouncil.org.uk/news-opinion/double-diamond-15-years - [Accessed 11/11/19]

[54] MSc in Disability, Design and Innovation (processes and techniques) GDI Hub.

[55] Parent/Caregiver Perspectives on power wheelchair - https://journals.lww.com/pedpt/pages/articleviewer.aspx?year=1996&issue=08040&article=00002&type=abstract - [Accessed 13/11/19]

[56] A wheelchair can be fun: a case of emotion-driven design - https://dl.acm.org/citation.cfm?doid=782896.782903 - [Accessed 13/11/19]

[57] Practice considerations for the introduction and use of power mobility for children - https://www.ncbi.nlm.nih.gov/pubmed/23998510 - [Accessed 13/11/19]

[58] American and Canadian therapists' perspectives and practices - https://onlinelibrary.wiley.com/doi/full/10.1111/dmcn.13960 - [Accessed 13/11/19]

[59] Children's, Parents', and Occupational Therapists' Perceptions - https://www.tandfonline.com/doi/full/10.1080/01942638.2018.1496964 - [Accessed 13/11/19]

[60] Participatory photovoice narrative study… - https://www.tandfonline.com/doi/abs/10.1080/17483107.2018.1447606 - [Accessed 13/11/19]

[61] Impacts of early powered mobility provision on disability identity case study - https://www.ncbi.nlm.nih.gov/pubmed/30570332 - [Accessed 13/11/19]