The order and priority of research and design method application within an assistive technology new product development process: A summative content analysis of 20 case studies.

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Implications for Rehabilitation

The communication highlights a number of issues that have implication for those involved in assistive technology new product development:

- The study defined over 200 well-established research and design methods and design heuristics that are available for use by those who specify and design assistive technology products, which provide a comprehensive reference list for practitioners in the field;
- The review within the study suggests only a limited number of research and design methods are regularly used by industrial design focused assistive technology new product developers; and,
- Debate is required within the practitioners working in this field to reflect on how a wider range of potentially more effective methods and heuristics may be incorporated into daily working practice.

Abstract

Summative content analysis was used to define methods and heuristics from each case study. The review process was in two parts: 1) A literature review to identify conventional research methods; and, 2) a summative content analysis of published case studies, based on the identified methods and heuristics to suggest an order and priority of where and when were used. Over 200 research and design methods and design heuristics were identified. From the review of the 20 case studies 42 were identified as being applied. The majority of methods and heuristics were applied in phase two, market choice. There appeared a disparity between the limited numbers of methods frequently used, under ten within the 20 case studies, when hundreds were available.

Keywords

Industrial design, research and design methods, design heuristics, assistive technology, product design

Introduction

When working with healthcare professionals in the early 1990’s, the author was challenged to ‘prove’ why the Assistive Technology (AT) product he had designed worked; not just in terms of functionality, but also its social function. It was at this

point the author realised he did not have a pathway to provide the required validation, starting a career-long study into suitable ways to validate AT product design within the context of Industrial design.

This article provided some insights towards answering the need for practicing Industrial Designers to effectively apply design and validation methods and heuristics when working in the field of AT product design; providing a bridge between theory and practice. There is a further debate relating to the benefits of providing a detailed structure for design activities versus the constraints it might bring to creativity, but this is beyond the scope of this study.

In the1990's the medical model of healthcare (treatment of symptoms) was being superseded by the social model (treatment of the person). (Conway 2008) The healthcare professionals also applied an evidence-based approach to medical intervention and expected the same evidence of efficacy AT products. Efficacy was considered to be the combination of effectiveness of an intervention and its cost-effectiveness.

To provide a fixed viewpoint for this review a definition is required for Industrial design and associated validation of efficacy. An Industrial Designer (ID) contributes to the social and cultural function, or value, by embedding cultural coding in a product or service, manipulating the viewer's or user's perceptions of it within the constraints of cost and time. Effectiveness may be validated through a mixed methods approach of qualitative and quantitative evaluation employing interview, observation, survey, product probes, comparison rating and eye tracking, force sensors, motion capture, galvanic resistance, all formally applied within research methods that include: task analysis, systems analysis and ethnography. AT product design is a subsection of Industrial design focusing on the provision of products (predominantly) that is used to increase, maintain or improve the functional capabilities of individuals with disability. (WHO 2016: 14) See Figure 1.

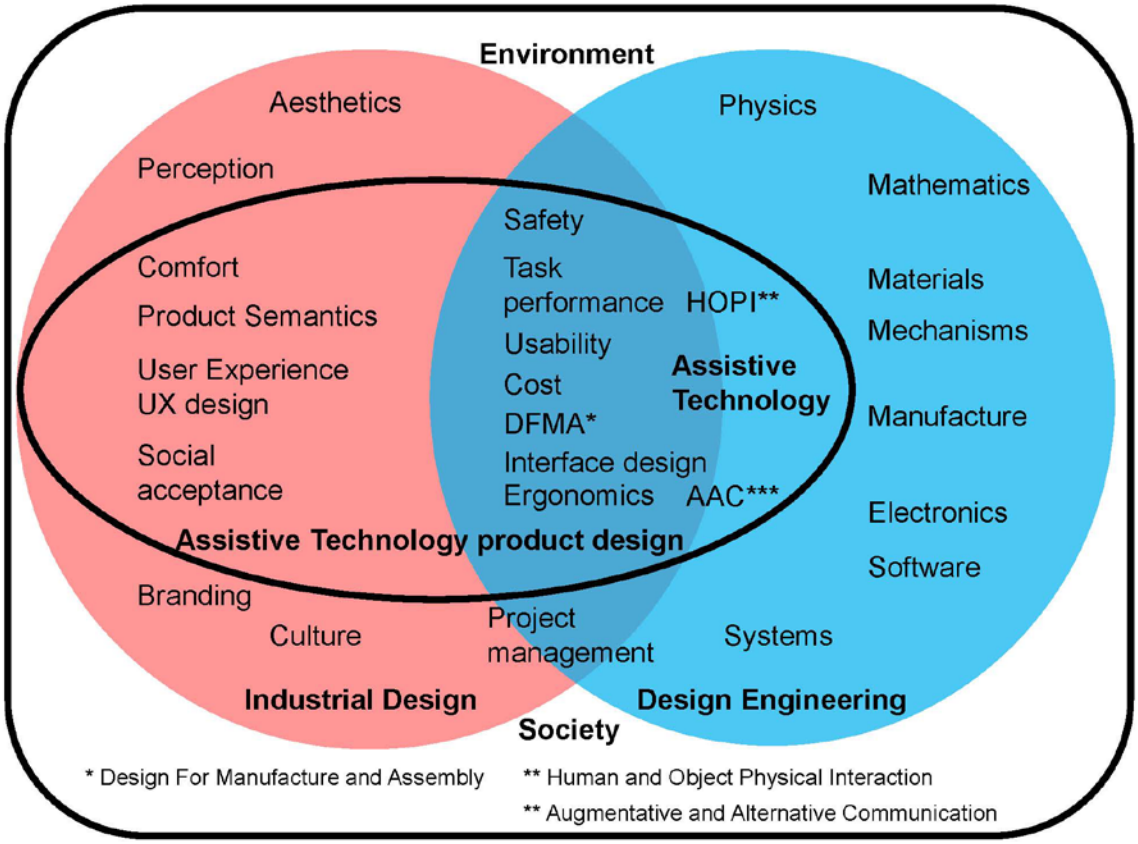

Figure 1. Assistive technology within Design and Engineering. (Torrens 2015)

The combination of social functionality and physical function within ID means that adoption of an engineering approach to product validation is not possible. In this context, social functionality is the individual and societal needs and aspirations for a product. The needs and aspirations may be aligned with Donald Norman's affordances (1999) or Patrick Jordan's four domains (2002). To enable validation beyond outcome, ID practitioners require a combination of both qualitative and quantitative research methods. Creswell (2009) and Plowright (2011) both advocate a mixed methods approach, which suits the needs of ID practitioners.

The application of research methods may be augmented by design methods and heuristics, which have been developed to enable an Industrial designer to develop a dialogue with their client, end users and stakeholders. The complexity of social and physical functionality embodied in a design solution is often presented as a 2D image or 3D object. Definitions were required to differentiate between research and design. Research methods were categorised under three main forms: exploratory; constructive; and, empirical research (Allison et al 1996: 6).

Design methods were defined as a systematic way of doing something within a sequence of operations actions or events that may be called a design process. (Jones 1970) In addition to systematic actions, the definition of a design method in this study includes applied knowledge or principles. The principles or rules offer structure to deductive reasoning within an evidence-based design decision-making

process. The evidence used in a deductive reasoning design process may be shown through the service or artefact. The decisions made to realise the product may be critically reviewed using an inductive approach.

The application of techniques and use of heuristics in a timely sequence provide the operator with a simplified set of variables on which design decisions may be made, within the complexity of a real-world problem. (Cross 1989) Design heuristics were defined as mental short-cuts or rules applied to ease the cognitive load when making timely design decisions. (O'Flynn and Waldmann 2011: 112) Heuristics were considered to be rules often based on past experience and learned behaviours, (e.g. rule of thumb). They were also considered be a collective consensus of opinion on a specific set of variables. (Martin and Hanington 2012: 98) Martin and Hanington suggested heuristics could help in categorising, organising or prioritising. Heuristics might also be used to generate options from which design decisions may be made.

The application of design principles, alongside design heuristics, produce an effective way of doing things. Although an inductive approach may be taken, the use of principles (theory) enables a potentially reliable prediction of outcome. The authors experience has been that Industrial design validation still relies heavily on success of the product in the marketplace, particularly within AT product design.

This article was written from the viewpoint of applied science, rather than a narrative or critical reflection. Based on the author's experience, Industrial Designers are more familiar with this format than reflective texts, as much of their work is closely aligned with Engineering.

Aim and objectives

The aim of this article was to provide design practitioners with insights into the order and priority of research and design method and design heuristic application within a new product development process (NPD), focused on Assistive Technology (AT) products.

The objectives were to:

- Identify available research methods, design methods and heuristics from literature;
- Critically review available literature to identify unique methods and heuristics and minimise duplication of purpose;
- Review 20 published AT product development case studies to identify when these methods are applied;
- Define a critical pathway of method and heuristic application; and,
- Identify any other characteristics that may be AT product design specific.

Summative content analysis

Summative content analysis was used to define methods and heuristics from each case study. (Hsieh and Shannon 2005) Content analysis may be considered a derivative of Thematic analysis (Braun and Clarke 2006).

The study explored the application of methods and heuristics through identified keywords within twenty case studies. The keywords were derived from a literature review and placed within a known context and structure. Bounding of the literature review limited expectations and focused on providing material that was within the professional practice of Industrial design within the field of Assistive Technology product design.

The review process was in two parts: 1) The identification of conventional research methods; and, 2) summative content analysis of published case studies to identify the order and priority of where and when defined methods and heuristics were used. See Figure 2. Case study is a research method involving in-depth and detailed examination of a subject of study (the case), within related contextual conditions or environments. (Cohen et al 2007: 34)

Literature Review

To help bound the field of design and research to be covered, a number of limitations were placed on the review. The limitations were based on an initial review of available material across all areas, using the online software “Library Catalogue Plus” (Ex Libris, 2016), a meta-search engine. Keywords initially used were: “research methods, design methods, design heuristics, Industrial design, Product design, Assistive Technology, Inclusive design, Universal design, User centred design”. The author found from the initial review that methods described in journal articles were often derivations or hybrids of conventional protocols. Articles and textbooks based in Engineering and Architecture brought a range of methods not usually applied by Industrial designers.

The focus of the main review was on the definition of existing and well-established research methods, design methods and heuristics. Methods and heuristics to be included were user-centred and human scale, hand-held or body-worn (including wheelchair accessories), which excluded predominantly engineering and architectural methods and heuristics relating to physical manufacturing, materials and systems. The context of the case studies was all from within the support and funding structures of United Kingdom (UK) based healthcare. Reference to other International healthcare structures and viewpoints were translated into or compared with a UK context. The terminology of definitions related to this field of Design discipline were from a UK context and perspective.

The design of medical products, such as those used in secondary care (Medical Hospitals) for example; interior design or architectural issues, such as accessibility and space design, was beyond the scope of this review. Similarly, issues of creativity and innovation were not considered in this review of methods for the pragmatic

reasons of the available time and resource to the author. Design decision-making was discussed, but in the context of efficacy of method. The journals and textbooks that were included assumed some background knowledge of design or engineering processes.

There was no time limit placed on the publication date of textbooks or articles reviewed as some research methods, such as paired comparison, were first described nearly a hundred years ago. (Thurstone, 1927)

The emphasis on well-established methods and heuristics focused the review on textbooks, Theses and standards. Research articles and conference papers were considered to present new and innovative approaches to research and design methods and design heuristics. New approaches to the application of existing methods or novel developments were less likely to have been widely used or demonstrated as effective. Standards in this context were British Standards relating to Industrial Design and Assistive Technology/Inclusive design. These standards related to design management of a new product development process.

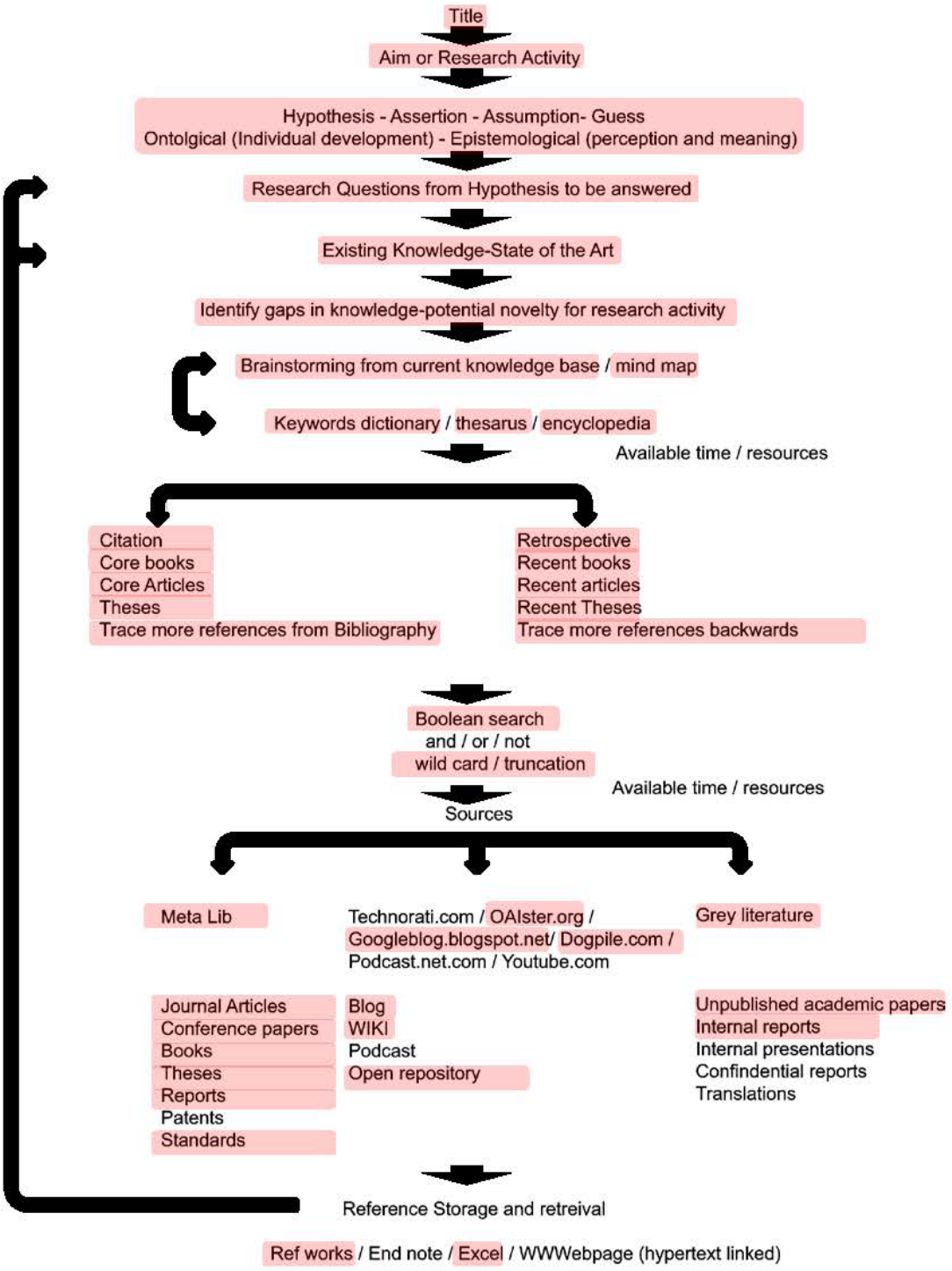

Figure 2. Literature review pathway.

There was an iterative cycle of review, including data mining of authors of interest and reference lists from within articles and textbooks. The keywords used in the initial survey were used for the main survey, as they were found to provide a manageable number of references within the limitations of an individual reviewer.

A list of methods and heuristics was complied. The author's experience and professional connoisseurship in the field of Industrial and Product Design were used

to make qualitative decisions about duplication of methods or heuristics from different sources. Methods and heuristics were initially identified by name, with each article or chapter checked to ensure they match the protocol conventions associated with them. Where not clearly defined the protocols described were used to identify the method or heuristic through matching to other similar descriptions in other texts, within the context of their application as a research or design tool.

Summative content analysis of case studies

The case studies were analysed to A) Identify methods and heuristics employed; and, B) the point at which they were used during the design process described in the associated article or chapter.

Twenty case studies from the field of Assistive Technology product design were identified and selected from available sources, including Journal articles and textbooks. Ten were from the author, spanning a fifteen year period, with ten from other authors over the same period. Studies from other authors were chosen to match the level at which the ten author case studies were described: method only (Micro level); combined methods (Mezzo level); and, methodology or approach (Macro level).

Statistical validation of outcomes were mentioned in case studies, but not discussed in detail. They are not defined as a method in the literature review or thematic analysis outcome. The author's experience has been that the choice of statistical validation technique would be done with the advice of a statistician. The technique would be applied as part of the post-processing of data, a sub-section of a method.

The format of the British Standard BS7000-6: 2005 (British Standards 2005) was used to categorise and sequence a design process. These were mapped onto existing design references that defined a design process. The five phases of Martin and Hanington (2012) were through to best match on to the British Standard and a 'double-diamond' diagram of a new product development process promoted by the Design Council in the United Kingdom. (2016) See Figures 3 and 4.

The author considered that beyond stage 7 of the British Standard was effectively a repeat of the Martin and Hanington phase 1, within the context of Industrial design. For practical purposes, phase 1 of the Martin and Hanington phases was repeated in phase 5 of the table. This conclusion was based on the need to review the product launched in stage 7/end of stage 4 as a new product, defining new markets, insights and developing propositions to modify the existing design. The methods and heuristics appropriate for this task are the same or similar to those in phase 1. More specific methods for phase 5 from engineering and business management were not included, as they were considered outside the focus on ID practice.

The ten papers from the author were used to develop a template protocol for the analysis and the identification of keywords (specified methods and heuristics) within

the text; the sections of a new product design process described in the case study; and, the points at which the methods and heuristics were used within the described design process.

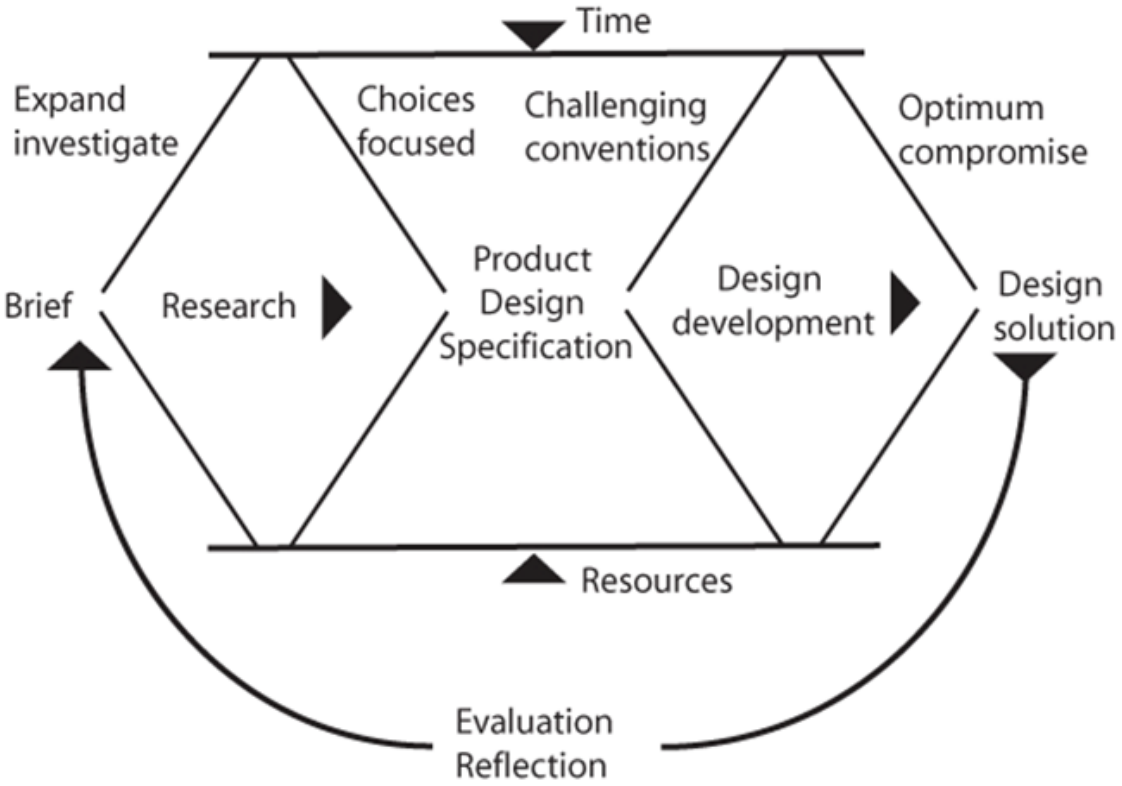

Figure 3. Design development process promoted by the Design Council (1986), modified by the author (Torrens 2012).

To minimise bias, the twenty case studies were reviewed by two operators, using the same protocol. The list of methods and heuristics were supplied to both operators, along with a short description of each of the Martin and Hanington phases. (See Table 1.) They were also supplied with a list of defined research methods, design methods and design heuristics from the literature review. (See Tables 1, 2. and 3.) The operators used Tables 1, 2, 3 and 4. to identify those used in each study and at what point in the five phases they were applied. One operator was the author, the other an administrator with a good working knowledge of design methods. Using an operator not fully immersed in design methods was to ensure the descriptions were reviewed on the content alone; to avoid the operator unintentionally ‘filling in’ any gaps using past experience of the methods.

The two reviews were compared to identify any anomalies or other differences between each reviewer’s interpretations of each case study. If any differences were found, they were to be discussed and highlighted. Where one operator had identified a method or heuristic and not the other, the reasoning for identification was to be

discussed and the element included or excluded. Due to constraints of time and resource consideration was not given to any excluded identified methods or heuristics being novel or a new category being needed. Where there was a difference of opinion in placement of method or heuristic within the five phases or multi-use phase the same format of discussion was to be applied to come to a decision on that element's position within the phases. The externalisation of operator reasons for choices made was also to resolve differences of interpretation.

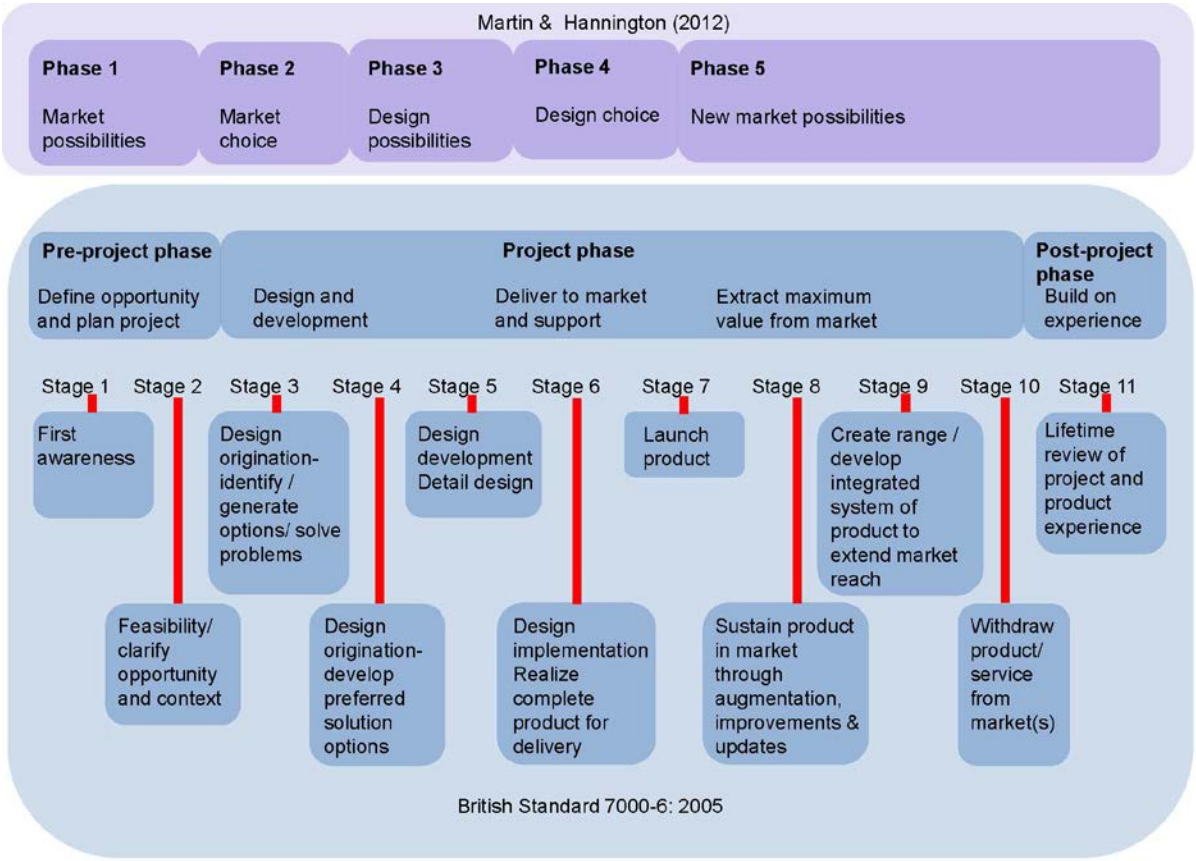

Figure 4. A comparison of the five phases of Martin and Hanington (2012) and the defined phases within the British Standard 'Managing inclusive design' (British Standard 2005).

A critical path analysis (Fondhal 1962) was then to be applied by the author to the identified methods and heuristics from the twenty case studies to group and order their application. (See Table 3.)

Table 1. Description of Martin and Hanington five phases, based on the requirements of BS7000-6:2005.

Martin & Hanington 5 Phases augmented with descriptions from BS7000-6:2005.				
Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Market possibilities; Planning, scoping and definition; project parameters explored and defined; first awareness; feasibility, clarify opportunity and context; insights; gain consensus.	Market choice; exploration, synthesis and design implication; immersive research and design ethnography; design origination-identity, Brand, generate propositions/solve problems; propositions; Ideation; generation of product design specification; validate with market; individual and consensus.	Design possibilities; concept generation, early prototyping iteration, participatory and generative design activities; design origination-develop preferred solution options; design development; detail design; validate with market; gain consensus.	Design choice; evaluation, refinement and production; iterative testing and feedback; design implementation; realise complete product for delivery; testing and validation to standards and industry guidelines; Launch product.	New market possibilities; monitoring of product in market; awareness of new markets; feasibility, clarify opportunity and context; insights; sustain market through improvement; create range/develop integrated systems of product to extend market reach; lifetime review and product experience.

Results

Over 150 references were reviewed in the Literature review (see Bibliography). A consensus on identification could be made for many of the conventional research methods, such as observation, literature review and interview as they were described in multiple textbooks. It was more difficult to identify methods and heuristics that were AT product design specific, as they were less frequently reported.

Following the literature review, 10 references in total were used as the descriptors for all the methods. Martin & Hanington (2012), Lidwell, Holden & Butler (2003) and Wilson & Coreltte (2015) provided the bulk of the descriptions, with Papanek (1974). A description of Delphi Study from Green (2014), Benchmarking, (Edwards 2016, Tutton 2009) and Grounded theory (Bryman: 401) were included along with AT specific ID methods from the author (Torrens 2013: 233-248, Torrens and Gyi 1999: 217-226). The majority of methods and heuristics were also defined in other texts, but this group provided the maximum number of descriptions for least number of references from which to refer. Where journal articles had been referenced, or a Thesis in the case of the Delphi study, it was to apply the most accessible and complete definition of the method or heuristic.

Operators looked for the defined methods and heuristic titles within the text. This was equivalent to keywords within a generic summative content analysis protocol.

They then reread the text to compare the task to which the identified method or heuristic was being applied to match them to the correct title in the list within Tables 2, 3 and 4. The second reading provided a contextual check for the operator relating to their choice. Appendix 1 shows the intermediate step of methods and heuristics identification and ordering against each case study prior to summary in Table5.

When comparing the two reviews the main difference was that the practitioner immersed in design defined more methods than the operator from a non-design background. From discussion, the design practitioner had defined activities that were not explicitly described.

Table 2. Shows 59 defined research methods.

Research methods,		
A/B Testing	Experiments	Role play
Artefact analysis	Exploratory research	Secondary Research
Automated remote research	Eye tracking	Semantic differential
Behavioural mapping	Fly on the wall observation	Shadowing
Case studies	Focus group	Site search analytics
Comparison	Generative research	Stakeholder walk through
Competitive testing	Graffiti walls	Surveys
Content analysis	Grounded theory	Task analysis
Contextual enquiry	HOPI	The love letter and the break up letter
Critical incident technique	Interviews	Think aloud protocol
Crowdsourcing	Laddering	Touchstone tours
Cultural probes	Literature reviews	Triading
Customer experience audit	Mixed methods	Triangulation
Delphi study	Paired comparisons	Unobtrusive measures
Desirability testing	Personal inventories	Usability Evaluation
Diary studies	Photo studies	Usability testing
Directed storytelling	Questionnaires	User journey maps
Ergonomic analysis	Ranking	User, Task Environment Characterisation
Evaluative research	Remote Moderated Research	Web analytics
Experience sampling method	Research through Design	

From the 20 case studies 42 methods and heuristics in total were identified. Of these 20 were research methods; 17 were design methods; and, 5 were design heuristics. See Table 5. The Table also shows the second phase of review, which was to place the methods and heuristics within the defined five phases or multi-use phase.

Steps were taken to identify the phase into which each method or heuristics would be placed involved re-reading each case study. The phases each case study described were considered and used to then place the method or heuristic in the appropriate phase.

Table 3. Shows 28 defined design heuristics.

Design heuristics		
80/20 rule/ Pareto's principle	Five-hat racks	Picture cards
AEIOU	Flexibility usability trade-off	Scenario description swim lanes
Brainstorm graphic organisers	Heuristic evaluation	Stakeholder maps
Card sorting	Hierarchy of needs	Thematic networks
Cognitive mapping	Kano analysis	Usability report
Cognitive walk-through	Key Performance Indicators	Value opportunity analysis
Collage	KJ technique	Weighted matrix
Cost-Benefit	Mental model diagrams	Word Clouds
Depth of processing	Mind mapping	
Elito method	Personas	

Table 4. Shows 117 defined design methods.

Design methods		
Accessibility	Factor of Safety	Participatory design
Advance organiser	Feedback loop	Performance load
Aesthetic usability effect	Fibonacci sequence	Performance vs Preference
Affinity Diagramming	Figure-ground relationship	Picture superiority effect
Affordance	Fitt's law	Progressive disclosure
Alignment	Forcing new thinking patterns	Prospect refuge
Archetypes	Forgiveness	Prototyping
Attractiveness of bias	Form follows function	Proximity
Baby-face bias	Framing	Readability
Benchmarking	Garbage in garbage out	Recognition over recall
Bionics	Golden ratio	Redundancy
Champion user	Good continuation	Rule of thirds
Chunking	Gutenberg diagram	Satisficing
Classical conditioning	Hick's law	Savanna preference
Closure	Hierarchy	Scaling fallacy
Codesign	Highlighting	Scenarios
Cognitive dissonance	Iconic representation	Self-similarity
Colour	Image boards	Serial position effects
Common fate	Immersion	Shaping
Confirmation	Interference effects	Signal to noise ratio
Consistency	Inverted pyramid	Similarity
Constancy	Iteration	Simulation exercises
Constraint	Law of Pragnanz	Standardisation
Control	Layering	Storyboards
Creative tool kits	Legibility	Storytelling
Defensible space	Lifecycle	Structural forms
Design charette	Mapping	Symmetry
Design ethnography	Mental model	Technology footprint
Design workshops	Mimicry	Threat detection
Development cycle	Mnemonic device	Three dimensional projection
Empathic modelling	Modularity	Top-down lighting bias
Entry point	Most average facial appearance effect	Uncertainty principle
Errors	Normal Distribution	Uniform connectedness
Evidence-based design	Ockham's Razor	Visibility
Expectation effect	Operant conditioning	von Restroff effect
Experience prototyping	Orientation sensitivity	Waist-to-hip ratio
Expert Review	Parallel prototyping	Wayfinding
Exposure effect	Participant observation	Weakest link
Face-ism ratio	Participatory Action Research (PAR)	Wizard of Oz

Table 5. shows critical path analysis of the application of design research methods and heuristics within an AT product development.

Research methods, design methods and design heuristics	Research Method A	Design Method B	Design Heuristic C	Phase 1&5	Phase 2	Phase 3	Phase 4	All Phases 6	Frequency of use identified within 20 case studies
Design ethnography		B		1&5					4
Empathic modelling		B		1&5					4
Mental model		B		1&5					4
Brainstorm graphic organisers			C	1&5					3
Cultural probes	A			1&5					1
Grounded theory	A			1&5					1
Task analysis	A				2				18
Usability Evaluation	A				2				17
Experience prototyping		B			2				13
Interviews	A				2				11
Performance vs Preference		B			2				11
Evaluative research	A				2				6
Image boards		B			2				6
Ranking	A				2				5
Value opportunity analysis			C		2				5
Desirability testing	A				2				4
Role play	A				2				3
Storyboards		B			2				3
HOPI	A				2				2
Codesign		B			2				2
Modularity		B			2				2
Artefact analysis	A				2				1
Standardisation		B			2				1
Thematic networks			C		2				1
Surveys	A					3			9
Questionnaires	A					3			6
Personas			C			3			1
Visibility		B					4		11
Expert Review		B					4		9
Comparison	A						4		4
Paired comparisons	A						4		1
Performance load		B					4		1
Case studies	A							6	20
Literature reviews	A							6	20
Participant observation		B						6	17
User, Task Environment Characterisation	A							6	15
Mixed methods	A							6	12
Focus group	A							6	11
Stakeholder maps			C					6	9
Participatory Action Research (PAR)		B						6	7
Evidence-based design		B						6	3
Benchmarking		B						6	2

The review from each operator was again compared as applied in the first review of titles. The operators discussed differences to resolve any issue of placement. The activity appeared more straightforward as the scope of each study had been defined along with keyword titles for methods and heuristics.

The outcome of the review identified that 6 methods and heuristics were used in phases 1 & 5; 18 were used in phase 2; only 3 in phase 3; and, 5 in phase 4. 10 had been identified as being potentially used across all phases.

The frequency of application across all 20 case studies was used to prioritise the methods in each phase. The high frequencies of methods or heuristics applied could have been predicted for each phase: design ethnography, empathic modelling and mental models in phase 1 & 5; task analysis, usability evaluation and experience prototyping in phase 2; surveys, questionnaires in phase 3; visibility (methods of use clearly visible) and expert review in phase 4; and, literature review, participant observation and user, task, environment characterisation across all phases.

Of the 42 methods and heuristics, only 12 were used in more than half the studies. Nearly half of the methods and heuristics, 20, were used in less than 5 studies.

Conclusions

The study was based around opinions of a small number of individuals. Whilst valid as a discussion point, the outcomes would potentially be difficult to replicate from this initial study. The summative content analysis would appear to work well for this application and context. A consensus on the definition of methods and heuristics and their categorisation would help make the analysis more reliable; more deductive than inductive.

The literature review was an initial sorting of methods and heuristics. The literature review has provided a statement of the classification of research methods, design methods and design heuristics. There are similar generic classifications in the Martin and Hanington; Lidwell, Holden and Butler references; and, more specific classifications in references by Clarkson et al.

The similarities and differences between what was presented in the study and other available classifications should be debated. For example, visibility, as described by Lidwell et al (2003: 202), relates to systems that are more usable when they indicate their status, the possible actions that may be performed and the consequences of those actions. They cite Design of everyday things (Norman 1990) as the reference for this description. The interpretation by the operators of this design method when reviewing the case studies encompassed the communication of use. If considered in more detail, within context of phase, the range of design methods that were selected as communicating use could have been wider. However, there was a constraint of review time per method selection in this study.

A consensus is required into which category each activity described should be placed, within the context of Industrial design practice and AT product design.

Many of the activities defined as design methods are currently describing principles to be applied by designers, rather than the steps taken in application. There is more required of design researchers and educators to define these steps for new and practising designers; to link theory and practice.

From the case studies reviewed the link between research methods and the design interventions they validate does not appear to be well defined. Further discussion and debate is required.

What can be taken from the information provided is that whilst there are hundreds of methods and heuristics available the majority of studies reviewed from the AT product design field appear to apply less than quarter, with the majority applying less than ten. The case studies did provide an outline of the section of a design process they described. However, the requirement to provide a detailed outcome within the word limit of a journal article has resulted in limited discussion to the methods and heuristics of interest. The majority of the 20 studies alluded to work outside the focus of the communication. Further work is required to communicate to ID practitioners in this field the research methods, design methods and design heuristics available for use within their design process.

Table 5 may be used as a ‘Look-up table’, effectively becoming a design heuristic. The placing of methods and heuristics within the context of a standardised design process as shown in Table 5 may be considered a positive step towards students and practitioners to be more confident in their choice for application.

There is a debate needed between academics and practitioners to provide an accessible and useful taxonomy of methods and heuristics for use by students and practitioners in industry. The current online resources such as Usabilitynet (Usabilitynet 2016), Inclusive Design Tool kit (Inclusive design tool kit 2016), Usability-NET (Usability-NET 2016), and EDeAN, (EDeAN 2016) go some way to providing this, but more explicit and detail descriptions of each method are required.

The author welcomes further discussion and debate to bridge the gap between design intervention, through application of design principles, and its validation using available research methods.

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