Chapter 1
Standardization of Terminologies for Physical Models in Design Process

T. N. Subramanya and B. K. Chakravarthy

Abstract This paper proposes a generalized approach to classify physical models, considering the existing classifications by researchers in the past. The terms like models, mock-ups, prototypes, etc. are used to convey different meanings at each stage of the design process which lacks clarity. Although many high-level classifications of the physical models exist, the information available is very little and conflicting. A detailed guideline-based approach across a design process is required which is not rigid but flexible without infringing on the importance of language in creativity. The first part of the paper describes the role of physical models in design. The second part explains existing classifications and the underlying factors for classification and lists a set of guidelines to generalize the classification and standardize the terminologies. The third part of the paper proposes a set of terminologies to classify the physical models across different phases of the design process.

1.1 Introduction

Designing is a complex activity, and the outcome involves manipulation of the designer's internal representations which is key to innovation. However, the inadequate internal representations give rise to the need for external representations of the idea. A designer should have the ability to represent an object/idea in some form in a space to act as a stable display for him to manipulate easily so that he can creatively iterate to arrive at a solution [1]. In the early phase of the design process, designers use various external representations in capturing and developing initial fragile ideas, and physical model making is an established method of external representation. Physical models are of various types ranging from quick and dirty

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A. Chakrabarti (ed.), *Research into Design for a Connected World*,
Smart Innovation, Systems and Technologies 135,
https://doi.org/10.1007/978-981-13-5977-4_1

mock-ups to accurate to scale prototypes for relection, evaluation and communication.

Physical models have been instrumental over the centuries in producing innovative representations and forms to connect better with the expectations of different stakeholders [2, 3]. Designers have been using physical models to ideate, visualize and evaluate the ideas and concepts across all phases of the design process. Prior research promotes the use of physical prototyping as an effective tool to generate and develop new ideas, as the physical prototypes supplement and improve designer's incorrect mental models and enhance creativity and functionality of the ideas [4]. Also countering this view, other researchers warn designers to think before using physical prototyping as it can introduce fixation due to various factors like time and cost or 'functional' and 'mental set' fixedness [4].

Many researchers in the past have advocated using physical models in idea generation phase, where the ideas are still fluidic in nature which can be improvised easily as physical models help the designers to externalize the thought process for better visualization and reworking. Isa and Liem [5] describes model making (mock-ups) as a way for designers to explore form, composition and functionality from idea to detail design. Compared to sketches and virtual prototypes, by using the physical models, the designer can get clear insights about form, function and construction. Referring to three-dimensional sketching (model making), Rowena Reed opines that the 3D forms reflect the direct visual experience of the thing, how forms and spaces and movements 'speak' to one another [6].

Primarily, the terminologies like 'physical models' or 'prototypes' are borrowed from other fields like mechanical or manufacturing domains and are not relevant to all phases of the design process. Researchers have classified physical prototypes based on factors like the design process, materials used, purpose, dimensions, stages, fidelity, etc. So far, no standard set of terminologies are followed in classifying the physical models. After reviewing the literature from many researchers in the past, one can come to the conclusion that the terminologies used in defining the physical models at various stages of design process are not standardized and the information available is very little and conflicting.

1.1.1 Comparing Sketching and Physical Models

Till recently with respect to external representation, studies were conducted mainly on sketching or absence of sketching to understand the characteristics of imagery [7]. Physical prototypes are less studied compared to sketching which is an object frozen in time and form and a fluid structure changing its appearance and meaning. External representations, especially the physical models, allow the designer to pick up the inherent design flaw early and rapidly change it in the mental simulations. Affordances of physical models may better facilitate the mental simulations compared to sketching or no external representations.

Sketches support visual perception well, but do not support other sense modalities (haptic, gustatory, auditory and olfactory) which the physical models support suggesting that the physical models will be superior to sketches in perception in some but not all modalities. Also, the cognitive support offered by physical models reduces mental simulations more than sketches [1]. Mental simulations are of two types: the first one supports the functional and mechanical simulations, and the second one supports the end-user behaviour or the usability; both of them are well supported by the physical models compared to sketches. However, if uncertainty is considered as the primary factor and key driver in new inventions in design arising out of inadequate internal representations, sketches provide more uncertainty because they are purposefully ambiguous and allow for creative re-interpretations. Since the mind constructs an object internally in three-dimension, externalizing it in three-dimension would produce more accurate representation and also it corrects the incomplete or incorrect mental model based on which the object is constructed (Fig. 1.1).

This leads to a situation where a combination of sketching and prototyping being used to maximize the advantages of both representations as multiple forms of representations leads to better understanding, acquisition and memorization of the concept [8].

1.1.2 Comparing Physical Prototypes with Virtual Modelling

The influence of computers and digital devices has entered in every part of our life, and today designers use it even in the ideation phase. Although they help in other aspects of professional work for a designer like communication and collaboration in the design process, in its contribution to ideation, it has introduced rigid constraints

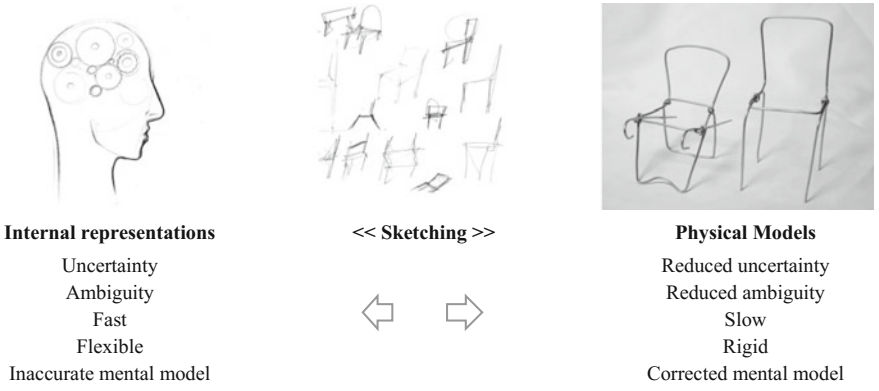

Fig. 1.1 Internal representations, sketching and physical models [22]

for the designer [9]. There is a dependency on the tool, and the designer is confined within the limits of the digital environment and also within the designer's skill level of the tool.

The physical forms inhabit the real space of the viewer compared to the imaginary space of the virtual models. Models constructed manually benefit from spontaneous juxtapositions and serendipitous interactions with light and gravity. Converting these models into the digital realm allows the computer to take over in areas that it does best: geometric transformation, rigorous analysis, elaboration and coordination of details and complexity [10].

1.2 Existing Classifications of Physical Models

Hallgrimsson defines 'prototyping' as a design method that uses physical prototypes to study and test the new concept with respect to form, function and usability. He further defines 'model making' as a step-by-step instruction to make a 'prototype' [11]. Other researchers like Kojima define physical model making as the next logical step in thinking process for every design idea [12]. Kelly strongly recommends in using it in design process where ideas are bettered using materials and fabrication techniques implying that each designer is served by a model making approach while translating an idea into reality [13]. Isa and Liem [14] describes soft model as a rough model representing the idea for assessing overall size, shape and proportion of the proposed idea.

As per Ulrich and Eppinger [15], a prototype is an approximation of the proposed product idea in one or more dimensions. The dimensions can be:

A. **Physical or analytical**: Physical prototype is an object which looks similar to the final product whereas analytical models are intangible like mathematical model.
B. **Focussed or comprehensive**: A focussed model can be a part or parts of the concept, and a comprehensive model has a holistic approach.

There are many classifications of mock-ups/models/prototypes by different researchers which are as follows (Table 1.1).

All kinds of easy to deform materials can be used to construct which is easy to shape and manipulate for fast evaluation of form and function, also depending on the feedback, the soft model can easily be changed. The designer adopts a more reflective way of shaping and moulding the model by hand continuously analysing it. Soft models are instrumental for designers in translating their ideas into reality and give next clear directions for the creative stages of the design process. It is easy to make changes to the soft model in the early stages, and the modification cost goes higher exponentially towards the final stages of the process. Hard models are technically non-functional but close replicas of final product, and it takes time to make these models. Presentation models are constructed through CAD data and

Table 1.1 Classification of physical prototypes by various researchers

Author(s)	Classification of mock-ups/ models/prototypes	Observation
Kojima [12]	• Image models • Rough mock-up models • Presentation models • Prototype models	Sketching included along with physical models
Mascitelli [24]	• Initial rough models • Refined models • Formative prototypes • Refined prototypes	4-level classification with models and prototypes as basic divisions
Ullman [25]	• Proof of concept • Proof of product • Proof of process • Proof of production	Classifies models based on functionality
Ulrich and Eppinger [15]	• Soft model • Hard model • Control model • Prototype	Simplified version based on material and purpose
Isa and Liem [14]	• Soft model • Hard model • Presentation model • Prototype	A combination based on the previous researchers' classification

control drawings which are fully detailed. The prototype is divided into formative prototype for user evaluation or summative prototype which is fully finished before production.

1.2.1 Limitations of Physicals Models

Many researchers believe that the designer should be careful in resorting to model making as a lot of time effort and resource are involved which in the course of time may influence the decision and design directions. This limitation is known as design fixation, but this view is countered by the observation that the fixation is a general phenomenon and is induced by many other factors which is present in all other types of representations [1, 16].

According to the studies conducted so far, there are conflicting results as it was found that there is high degree of fixation as per Christensen and Schunn [1] and no fixation as per Viswanathan and Julie [4]. Others emphasize that choosing the right type of physical prototype plays a very important role in generating high quality of ideas and suggests that in idea generation stage, less detailed high-level physical prototypes are more effective [17, 18]. This also indicates that choosing the right kind of prototype and building material also influences the fixation.

In the context under consideration, design fixation can occur due to the following factors [4]:

- Time
- Prototype building process
- Constraints present in building materials
- Sunk cost
- Anticipated cost.

1.2.2 Guidelines for Classification

Observations of the different classifications indicate that the current classifications are at high level and do not cover all aspects of the industrial design process. A set of following guidelines emerged from the literature study, discussions with academicians, students and industry experts. These guidelines were used as a backdrop in exploring standardizations for physical models.

1. **The designer's workflow should be taken into account considering all forms of external representations**: A designer works by seamlessly moving between different forms of external representations especially between sketching and physical models. So far only Kojima includes image models, and rest of the classifications do not include the sketches. While standardizing the terminologies, both sketching and physical models should be taken into account.
2. **The iterations and refined versions of the models in the design process should be clearly indicated**: Iteration is key to evolution of design from a hazy idea to a full-scale prototype, and the iteration factor should be indicated in the terminology standardization.
3. **Ambiguity in terminologies should be avoided**: The terminologies currently used are not relevant to all phases of design process, especially in the ideation phase.
4. **Purpose and approximation should be evident**: A physical model is made for different purposes to analyse form, function and proportion. The degree to which the final product is to be approximated should be included where a certain set of attributes are considered while building the model.

1.2.3 Terminologies and Definitions

Understanding the definitions of various terms used for physical models forms the first step in standardizing the terminologies which are as follows:

Mock-up: This is a scaled or full-size model of something large that has not yet been built, showing how it will look or operate. Ulrich and Eppinger define mock-up as an initial and rough representation of design intent where the aim of the designer is to show something rather quickly than accurately [15]. A 'quick and dirty mock-up' takes less time in doing it and costs less.
Model: Models are three-dimensional representations of the proposed design usually in a scaled down version where the scale of the model is arbitrary [15].
Prototype: These are full-scale working models. According to Ulrich and Eppinger, it is an approximation of the product in one or more dimensions of interest, and Hallgrimsson defines the prototype as the three-dimensional representation of the product, service or system [11, 15].
Fidelity: According to the Oxford dictionary, it is the degree of exactness with which something is copied or reproduced. 'Low', 'medium' and 'high' are the attributes used indicating the level of approximation.
Idea: This is the most embryonic form of a new product or service. It often consists of a high-level view of the solution envisioned for the problem identified by the opportunity [19].
Concept: It has a well-defined form, including both a written and visual description, that includes its primary features and customer benefits combined with a broad understanding of the technology needed [19].

From the above information, it is evident that the term 'mock-up' is appropriate at the early stage of the design process, 'idea exploration phase', where the aim is to show something rather quickly than accurately and the designer is still working on the hazy and uncertain ideas to eventually evolve some of them into concepts which can be pursued further.

The level of approximation of a model across the design process can be indicated by low-, medium- and high-fidelity models, and for the later stages of the design process, where functional and user testing and acceptance is tested, the terms 'model' and/or 'prototype' are more appropriate.

1.3 Standardization of Terminologies

Based on the guidelines derived from the previous classifications and the definitions, the following categories are proposed. The models are broadly divided into three stages as follows:

- Stimulation mock-ups
- Presentation models
- Simulation models (Table 1.2).

Table 1.2 Proposed classification of physical prototypes

Physical/image models in design process		
Stage 1—stimulation mock-ups	**Stage 2—presentation models**	**Stage 3—simulation models**
Stage 1A—low-fidelity exploration mock-ups		***Stage 3A—formative prototype***
Image mock-ups		Comprehensive
Doodles		Focussed
Thumbnails		
Physical mock-ups		
Exploration form mock-ups		
Exploration function mock-ups		
Stage 1B—medium-fidelity conceptual mock-ups		**Stage 36—summative prototype**
Physical mock-ups		Comprehensive
Conceptual form mock-ups		
Conceptual function mock-ups		
Image mock-ups		
Concept sketches		
Closed group (within team)		**Open group**

1.3.1 Stimulation Mock-Ups

Stimulation mock-ups mainly deal with the ideation process where the mock-ups are made to reflect on the journey from an idea to a concept within designer or the team. As the name suggests, in this stage the mock-ups, both image and physical, are made to represent the vague internal representation to an external representation to evolve and nurture the fragile idea. A designer starts with initial sketches as doodles which evolve into thumbnails. At this stage, the designer can switch to 3D models either to have a feel of the form or function or both. Once the ideas are represented in 3D models, the designer further refines some or all of the mock-ups which are called conceptual mock-ups. Once the concept is clear in the 3D mock-ups, the designer can switch back to sketching where different ideas/concepts can be combined to make a new concept or a concept can further be refined during sketching. The mock-ups that are made in this stage will take very less time, and the materials used will be of less cost to avoid design fixation.

A. **Low-fidelity exploration mock-ups**: In this stage, as the name suggests, the mock-ups are made quickly with any available and easily deformable materials to represent an idea.

   Image mock-ups—Doodles and thumbnails: The design activity starts with a doodle and slowly evolves into a thumbnail. David Bramston in his book 'Basics of product design—Idea search' defines doodle as less intentional and

more abstract, and it is a result of subconscious mind, and it is not produced with much concentration, and due to the lack of clarity and presence ambiguity, the scribbles and marks of a doodle carefully placed in context. The thumbnails offer the first glimpse of an idea visually represented which aims to capture the essence of a concept [20] (Figs. 1.2 and 1.3).

At this stage, the doodles and thumbnails are called image mock-ups and the designer, after producing as many image mock-ups as possible moves to the next stage to make the 3D models.

Physical mock-ups—Form and function mock-ups: At this stage, the designer continues the ideation process by making three-dimensional models using easily deformable materials like paper, foam board, polystyrene foam, clay, wood, etc. Here, the intention may be to answer the designer's questions concerning overall form and function as Hallgrimsson [11] calls these as 'looks like' and 'works like' prototypes. When the mock-ups are made with respect to form, these are called 'exploration form mock-ups', and for function, it is called 'exploration function mock-ups'. A mock-up can also be made with respect to form and function, and in this case, it is called 'exploration comprehensive mock-up' or 'exploration form and function mock-ups'. While making the models from thumbnail sketches, the designer may fuse a few ideas and also develop a new idea entirely. The ideation process is still continuing at this stage (Figs. 1.4 and 1.5).

B. **Medium-fidelity conceptual mock-ups:** At this stage, the designer starts the iteration process and refines a few of the mock-ups from the previous stage or may come up with an entirely new mock-up based on the previous experience. Also, new concepts may emerge by combining two or more ideas.

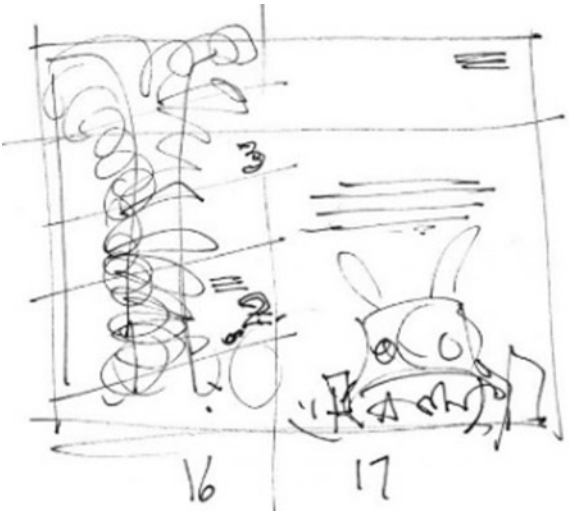

Fig. 1.2 Doodle [23]

Fig. 1.3 Thumbnail sketches of chairs [23]

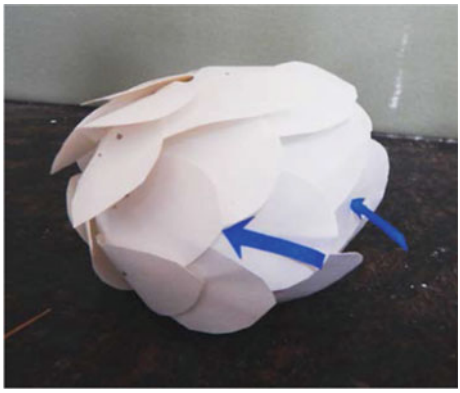

Fig. 1.4 Exploration form mock-up [22]

Fig. 1.5 Exploration function mock-up [22]

Fig. 1.6 Conceptual form mock-up [22]

Physical mock-ups—Form, function and comprehensive models: As the design evolves, a few of the mock-ups can be refined after several internal feedback loops. Although this step is separated from the previous step, in reality both the steps can be indistinguishable from each other. Also, many concepts can be fused to get a new refined concept or an entirely new concept can be evolved inspired by the mock-ups made in the previous step. The mock-ups made at this stage are called 'conceptual form mock-ups', 'conceptual function mock-ups' or 'conceptual form-function mock-ups' (Figs. 1.6, 1.7 and 1.8).

Image mock-ups—Conceptual sketches: Here, the designer continues the ideation process by getting back to the drawing table to sketch the final idea/s. With good knowledge about the form and intended function, the ideas are more distinct and functional. Refined image models along with refined physical

Fig. 1.7 Conceptual function mock-up [22]

Fig. 1.8 Conceptual sketches [22]

models can be used to evaluate and finalize the concept to decide the next directions.

1.3.2 Presentation Models

These models can be either image, virtual or physical, used to present the product concept to either stakeholders for sign-off purpose or users for marketing purpose. The presentation models are prepared after stimulation mock-ups to get a sign-off from stakeholders and/or towards the end for marketing and user feedback.

1.3.3 Simulation Models

Simulation models deal with testing the product concept for functionality and/or usability. The prototypes in this stage range from scaled to full-scale model of the proposed concept. The prototypes can be formative where the product is tested to get feedback to refine or summative where the prototype is being tested before mass production. The models made at this stage will take time, and material cost can be from moderate to high [14]. The prototypes can also be made by using the 3D printing technology where the models are virtually made and then printed using a 3D printer.

Formative prototypes—Functionality and/or Usability: Formative prototypes are made in either full scale or scaled version to simulate the product working/features so that it can be evaluated for the same. Formative prototypes can be focussed or comprehensive and also can be used to evaluate either functionality or usability. Formative prototypes still give scope for accommodating the feedback from stakeholders and users.

Summative prototypes—Functionality and/or Usability: Summative prototypes are made towards the end of the design activity to full scale with actual materials which go into making the product. Like formative prototypes, this is made to evaluate functionality or usability. The feedback from formative prototypes is addressed in the summative prototypes, and at this stage, the prototype is aimed at manufacturing and less changes are anticipated and accommodated.

1.4 Models Across Design Process

Various types of models are made during the different stages of design process to reflect upon the design. Models made at each stage are meant to answer a particular type of question in the designer's mind. Although the proposed set of terminologies are mapped across the double-diamond design process by Design Council, UK [21], the same set can be mapped on any other design process (Fig. 1.9).

The idea generation phase in the 'define' stage is divided into two subdivisions to accommodate the 'low-fidelity exploration mock-ups' which are made during

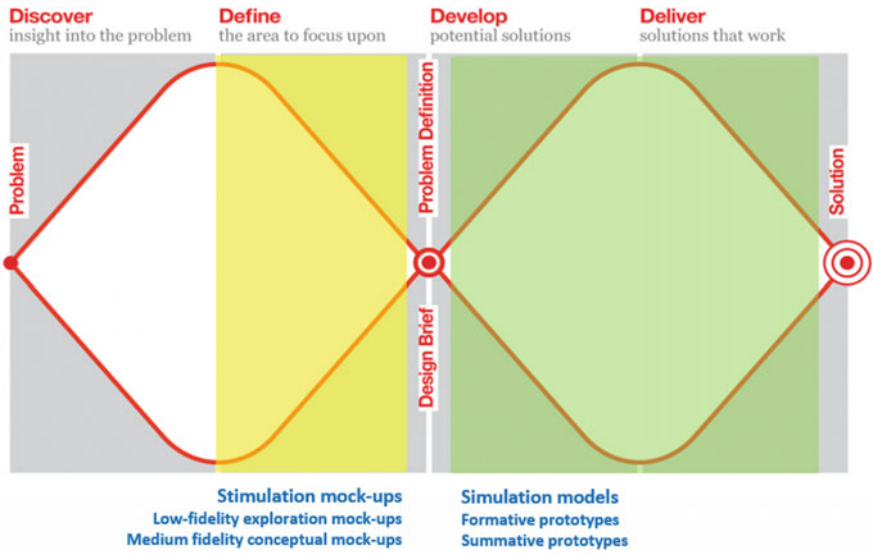

Fig. 1.9 Proposed terminologies double-diamond design process [21]

idea generation and 'medium-fidelity conceptual mock-ups' to arrive at concept stages by refining the mock-ups from the previous step. The designer/team while arriving at this stage would have generated several ideas and after careful self-evaluation would have refined/combined ideas into concepts. Concept finalization occurs at this stage as per the procedure of concept validation and the detailing of the concept begins. At this stage of the design process, the project sign-off phase requires the presentation models.

While detailing the concept in the 'develop' phase, the designer or the team to reflect on the design development builds formative prototypes which are used for validating with the users. The scale and the material of the model are decided by the purpose and availability of time, cost and effort. The formative prototypes are refined based on the feedback from peers, users and stakeholders until it is finalized. A summative prototype is built as the final prototype along with other deliverables for manufacturing the product which marks the completion of the first round of the project. During 'develop' and 'deliver' phase, the strength of the virtual models which are geometric transformation, rigorous analysis, elaboration and coordination of details and complexity can be made use. Further, current 3D printing technology can be used to build part or whole prototype.

The proposed set of terminologies at different stages of the design process compared to recent classification by Isa and Liem [14] are as follows (Tables 1.3 and 1.4).

Further discussions with academicians, industry experts and students gave few more options which are regularly used in the design activity such as quick and dirty mock-ups, creating exploration mock-ups, working rigs, working prototypes, full-scale mock-ups, montage, etc., and these can be overlapped with the proposed solution.

1.5 Discussion

The study highlights the importance of using physical models at all stages of the design process and also compares it with other representations. The proposed generalized standardization is independent of the design process and could be mapped across different design processes. This brings in clarity and precise understanding which helps the designer to make use of the unique strengths and advantages of physical models. A standardized set helps in communication in both reflecting upon the idea/product and communicating within or outside the team. Also compared to the classifications from the prior research which is at a high level, this paper attempts to go a detailed level classification.

The paper addresses the context of 'new product development' in industrial design and takes specifically the double-diamond design process as it followed and accepted by the industry in general and also takes into account the present-day scenario of synergy of other disciplines coming together with industrial design.

Table 1.3 Comparison of proposed terminologies with the classification by Isa and Liem [14]

Double-diamond design process	Isa and Liem [14]		Proposed terminologies		
			Level 1	Level 2 (optional)	Level 3
Discover					Final terminologies
Define					
Generation of initial ideas for new product or service or both (prototyping/mock-ups)	Soft models	Stimulation mock-ups	Low-fidelity exploration mock-ups OR low-fidelity idea mock-ups	Image mock-ups	Doodles
					Thumbnails
				Physical mock-ups	Exploration form mock-ups
					Exploration function mock-ups
	Hard models		Medium-fidelity conceptual mock-ups	Physical mock-ups	Conceptual form mock-ups
					Conceptual function mock-ups
				Image mock-ups	Concept sketches
Project sign-off (conceptual stage)	Presentation models		Presentation models (image/physical/virtual)		
Develop					
Development methods (working prototypes are developed)	Prototypes	Simulation models	Formative prototypes	Focussed/ comprehensive	Formative prototypes
Testing					
Deliver					
Final testing, approval and launch			Summative prototypes	Full-scale mock-up	Summative prototypes
Targets, evaluation and feedback loops					

Table 1.4 Accommodating alternate terminologies

Double-diamond design process		Proposed terminologies			Alternate terminologies
		Level 1	Level 2 (optional)	Level 3	
Discover				Final terminologies	
Define					
Generation of initial ideas for new product or service or both (prototyping/mock-ups)	Stimulation mark-ups	Low-fidelity exploration mock-ups OR low-fidelity idea mock-ups	Image mock-ups	Doodles	Scribbles
				Thumbnails	Montage
			Physical mock-ups	Exploration form mock-ups	Quick arid dirty mock-ups
				Exploration function mock-ups	Working rig
		Medium-fidelity conceptual mock-ups	Physical mock-ups	Conceptual form mock-ups	3D sketching
				Conceptual function mock-ups	
			Image mock-ups	Concept sketches	
Project sign-off (conceptual stage)		Presentation models (image/physical/virtual)			
Develop					
Development methods (working prototypes are developed)	Simulation models	Formative prototypes	Focussed/ comprehensive	Formative prototypes	Working prototype
Testing					
Deliver					
Final testing, approval and launch		Summative prototypes	Full-scale mock-up	Summative prototypes	Full-scale model
Targets, evaluation and feedback loops					

With sufficient knowledge and care, the physical models can be used to produce innovative yet functional ideas.

The scope of this work is limited to sketching and physical models and does not consider other representations like digital prototyping and 3D printing which could be included as the next step.

1.6 Conclusion

Handmade mock-ups involve more sense modalities which are body-centric, personal, tacit and tactile along with sketching. This allows for multidimensional expression giving clear directions for the next creative stages of the design process. Having the standardized set of terminologies brings clarity to the design activities and makes use of the physical prototypes at appropriate stages. A guideline-based approach of classification brings flexibility and does not infringe on the role of language in creativity. Since the set is not rigid, new terminologies can be accommodated as alternate terminologies by using the guidelines. A detailed set of terminologies helps the designer to not only understand the process but also in planning. The terminologies define the stages and level of approximation and suggest materials that should be used in making the physical model.

References

1. Christensen, B.T., Schunn, C.D.: The role and impact of mental simulation in design. Appl. Cogn. Psychol. Appl. Cogn. Psychol. **23**,327–344 (2009)
2. Sanders, E.B., Stappers, P.: Probes, toolkits and prototypes: three approaches to making in codesigning, CoDesign: Int. J. CoCreat. Des. Arts. **10**(1), 5–14. https://doi.org/10.1080/15710882.2014.888183
3. Charlesworth, C.: A student use of virtual model and physical modelling in design development—an experiment in 3D design education. Des. J. **10**(1) (2007)
4. Viswanathan, V.K., Linsey, Julie S.: Physical Models in Idea Generation—Hindrance or Help? IdETC/CIE 2010. Montreal, Quebec, Canada (2010)
5. Isa, S.S., Liem, A., Steinert, M.: The value of prototypes in the early design and development process. In: DS 80-5 Proceedings of the 20th International Conference on Engineering Design (ICED 15), vol 5: Design Methods and Tools-Part 1, Milan, Italy, 27–30 July 2015
6. Fasolino, W.: (2016). http://rowenafund.org/history/history-intro.html
7. Athavankar, U.: Mental imagery as a design tool (1997, 2017). https://udayathavankar.wordpress.com/2017/08/20/can-we-prevent-designer-from-sketching/
8. Dekeyser, H.M.: Student Preference for Verbal, Graphic or Symbolic Information in an Independent Learning Environment for an Applied Statistics Course, Ter Wadding, LZ Voorschoten, The Netherland (2015)
9. Hung, Shu, Magliaro, Joseph: By Hand: The Use of Craft in Contemporary Art. Princeton Architectural Press, New York, USA (2007)
10. Cheng, N.Y.: Linking the Virtual to Reality: CAD & Physical Modeling, Department of Architecture, University of Hong Kong, Hong Kong (1995)

11. Hallgrimsson, B.: Prototyping and Model Making for Product Design. Laurence King Publishing (2012). ISBN 9781856698764
12. Kojima, T.: Models & Prototypes. Clay, Plaster, Styrofoam, Paper, p. 37. Graphic Publishing Co.Ltd. (1991) ISBN: 4766106172 (Chapter 2)
13. Kelley, T.: Prototyping is the shorthand of innovation. Des. Manag. J. Summer 35–42 (2001)
14. Isa, S.S., Liem, A.: Classifying physical models and prototypes in the design process: a study on the economical and usability impact of adopting models and prototypes in the design process. In: DS 77: Proceedings of the DESIGN 2014 13th International Design Conference (2014)
15. Ulrich, K.T., Eppinger, S.D.: Product and Design Development, 5th edn. McGraw Hill Companies, Inc. (2012) ISBN 978-007-108695
16. Baxter, M.: Product Design: Practical Methods for the Systematic Development of New Products. Chapman & Hall, London (1996)
17. Houde, S., Hill, C.: What do prototypes prototype. Handb. Hum. Comput. Interact. **2**, 367–381 (1997)
18. Yang, M.C.: A study of prototypes, design activity and design outcome. Des. Stud. **26**(6), 649–669 (2005)
19. Koen, P.A., Ajamian, G.M., Boyce, S., Clamen, A., Fisher, E., Fountoulakis, S., Johnson, A., Puri, P., Selbert, R.: The PDMA ToolBook for New Product Development
20. Bramston, D.: BASICS Product Design 01, pp. 1–18. AVA Publishing SA, Switzerland (2009)
21. Design Council: Eleven Lessons: Managing Design in Eleven Global Brands, A Study of the Design Process, pp. 1–26. London, UK (2007)
22. Source from Industrial Design Class Project, 2nd Year Undergraduate and Graduate Students, 2016 and 2018
23. http://adaptanddesign.com/stemsteam-design/types-of-sketching/. Visited on 26 May 2018
24. Mascitelli, R.: From experience: harnessing tacit knowledge to achieve breakthrough innovation. J. Prod. Innov. Manag. 170–193 (2000)
25. Ullman, D.G.: The Mechanical Design Process. McGraw-Hill Professional, USA (2003)
26. McKim, R.H.: Experiences in Visual Thinking. Brooks-Cole Publishing Co., Monterey, USA (1972)