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The impact of LEGO and analog objects in co-creating and prototyping ideas

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ABSTRACT

The main purpose of this study is to examine the separate and combined efficacy of LEGO and analogue objects as prototyping tools in idea generation activities. The study took place in an environment where 'Design Jams' were conducted, involving 58 participants with diverse backgrounds. Results showed that LEGO and analogue objects encouraged designers and stakeholders to collaborate and think more critically through prototyping activities emphasizing experimentation, reflection, and decision making. Using co-creation methods, larger quantities of design solutions and longer-term design directions were generated through the establishment of a common visual language, the sharing of legitimate experiences, and improved decision-making.

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KEYWORDS
co-creation; prototyping tools; LEGO and analog objects

1. Introduction

Co-creation is a complex activity but is essential in understanding users-stakeholders and designers need with respect to anticipating future products and services (Isa & Liem, 2020; Nonaka & Takeuchi, 1995; Sanders & Stappers, 2014; Wolf, 2014; Zaltman, 2003). Moreover, co-creation facilitates teamwork and is considered one of the most efficient approaches in assuring commercial success (Ali & Liem, 2015; Prahalad & Ramaswamy, 2013; Sanders & Stappers, 2014). The user-stakeholder's involvement in the design and development process should be fully utilized by extracting many possible insights before finalizing end-user requirements.

The way designers currently engage with users and stakeholders is being contemplated as to whether or not it is the optimal method for generating ideas. As mentioned by Norman (2005), '*The best way to satisfy users is sometimes by ignoring them*'. This view has been supported by several cases involving end-users collaboration (Verganti, 2011). The actual contribution made by users was rarely considered important for design innovation since they were proposed by non-designers, who were perceived as not being able to properly articulate their needs (Norman & Verganti, 2014). However, others considered user-centered approaches invaluable for obtaining evidence-based information, particularly in determining user requirements during the initial development stages (Isa & Liem, 2015; Sanders & Stappers, 2014).

Additionally, Sanders and Stappers (2008), Isa and Liem (2020), and Prahalad and Ramaswamy (2013) suggested that designers should engage stakeholders and users more creatively and actively to extract tacit knowledge in the conceptualization of products and services. Besides this, information gathered from user's insights should be included and

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transferred through all stages of the design and development process, particularly the early stages, to facilitate product innovation. Although much research has been done on how prototyping methods and tools contributed to co-creation activities involving designer-user-stakeholders, much work is still needed to transform insights into strategic actions for anticipating future products and services. To ensure engaged participation of designer-user-stakeholder, designers employed a variety of tools and guidelines to enhance co-creation practises (Ali & Liem, 2015; Isa & Liem, 2020; Prahalad & Ramaswamy, 2013; Sanders & Stappers, 2014). Despite this, designers continued to struggle to grasp the concept of user-stakeholder's involvement as part of their studies. The reason is that without the assistance of adequate methods, techniques, and tools, user-stakeholder's involvement will not be impactful. Among the primary benefits of co-creation with future users or stakeholders is that designers will obtain an accurate assessment of the user's wants and needs, which serves as a validation of user requirements (Isa & Liem, 2020; Sanders & Stappers, 2014; Wolf, 2014). At the moment, designers and researchers are still attempting to devise an effective method for enabling people to contribute effectively during the initial design phase. It is unknown which customized design tools and techniques effortlessly contribute to the procedures. This is because certain design tools such as computer-aided design (CAD) modeling and sketching are losing their desirability due to high learning curves (Goldschmidt & Rodgers, 2013; Isa & Liem, 2014, Isa & Liem, 2020). Therefore, this study explores the advantages of using LEGO and analogue objects in the early design phases for co-creation with future users and stakeholders. The use of LEGO and its construction kits were emphasized, because of pre-defined elements and interfaces that allows LEGO bricks to be interconnected to create more complex structures. An emphasis has been placed on LEGO's practical value to develop physical representations (Boa et al., 2017; Isa & Liem, 2020). Although LEGO construction kits are effective in developing initial ideas during co-creation activities, its rigid adherence to orthogonal constructions and limited variety of elements (bricks) are one of the shortcomings (Boa et al., 2017; Isa & Liem, 2020; Mathias et al., 2017, 2019). Moreover, the lack of skills and experiences among participants and designers to address these shortcomings or exploit the most out of LEGO to facilitate 'creative' representation as much as possible, brings about the need to research the combined application of LEGO and analogue objects for prototyping in co-creation activities (Isa & Liem, 2020; Mathias et al., 2019). In this article, 'Analog Objects' refers to traditional 'Non-digital' objects that are tangible, affordable, and of low fidelity". Examples are paper, sticky notes, cardboard, straw, bamboo sticks, sponge, clay, etc. (Borum et al., 2014; Peters et al., 2020). According to Peters et al. (2020), ideating with analogue objects facilitates designers' collaborative work with diverse communities as materials are cost-effective, easily available, and suitable at any site independent of technological requirements (Inie & Dalsgaard, 2017; Isa & Liem, 2020; Peters et al., 2020). Although LEGO can be considered an analogue object, it is not defined 'analogue' in this article since LEGO is subject to a system with predetermined and easy to assemble characteristics. In this article analogue objects refer to something with low fidelity that must be cut, glued, or joined with other materials when prototyping. The goal of this study is to demonstrate the advantages of combining LEGO and analogue objects in co-creation activities, as these combinations may result in more diverse representations, the introduction and application of more integrated yet flexible prototyping tools, and an expansion of the creative space.

This following research questions were addressed with respect to this purpose:

RQ 1: What are the advantages and disadvantages of combining LEGO with analogue objects in co-creation activities?

RQ 2: What are the insights, using LEGO and analogue objects, to facilitate collaboration and communication among designers, end-users and other stakeholders during ideation?

2. Theoretical framework

This article has been positioned within multiple theoretical perspectives. These include generative tools in collaborative research (E. N. Sanders, 2000; A. Sanders, 2018; Sanders & Stappers, 2014); LEGO Serious Play methodology (Kristiansen & Rasmussen, 2014) for co-creation activities that was developed by the LEGO Group in 2010; and the SECI model of knowledge creation and transfer (Nonaka & Takeuchi, 1995). These theoretical frameworks support collaboration between user-designer-stakeholder through prototyping during co-creation activities.

LEGO and Analog Objects are framed as generative tools in collaborative research and design by emphasizing user's engagement in early development stages for (i) empowering participants, (ii) enhancing efficiency, and (iii) improving user's acceptance. These tools are classified into: (i) two-dimensional elements (paper shapes and colored photographs), (ii) three-dimensional elements (3D objects in multiple scales and sizes); and (iii) toolkits that were specially designed to elicit an emotional response from participants (Stappers & Sanders, 2014). LEGO and Analog Objects will also function as a common language between user-designer to enlarge the exploration space, develop better ideas and solutions, as well as create and transfer new knowledge.

Lego Serious Play (LSP) is an important step-by-step methodology to facilitate teamwork when developing ideas and design strategies involving multiple stakeholders to be applied in different inter-, and intra-organizational contexts (Kristiansen & Rasmussen, 2014, 2014). Through this methodology, participants will gain experience conducting experiments, formulating problems, and generating a broad diversity of ideas while developing and visualizing their thoughts.

To complement, the SECI model is fundamental for knowledge creation and transfer based on how knowledge can be combined, converted, created, and shared in collaborative work. Therefore, it is important for designers to directly engage users early in the design process to extract tacit knowledge, anticipate hidden needs, and facilitate knowledge sharing and ideation (Nonaka & Takeuchi, 1995). Figure 1 shows how the SECI model position generative prototyping tools (LEGO and analogue objects) and LEGO Serious Play as part of explicit and tacit knowledge cycles.

3. Research approach

Qualitative research methods, as promoted by Creswell and Poth (2016) and Chih-Pei, & Chang (2017), were used to investigate more in-depth how LEGO and Analog Objects contributed to co-creation processes. Being acknowledged as a suitable approaches for co-creation and creative problem solving (Snow et al., 2019; Van Waart et al., 2015), Design Jams were chosen by the researchers as the main qualitative research method to obtain a deeper understanding of the participants' experiences, their perspectives, and practices. According to Snow et al. (2019), Römer et al. (2011), and Van Waart et al. (2015), Design Jams are appropriate to be used during generative research, because it is participatory in nature, and stimulates the creative 'act of making' when applied to design research. This approach has been used to help organizations, teams, and individuals improve their thinking, communication, and problem-solving skills. Design Jams, which have been proven to be effective, are now widely used by many organizations (Snow et al., 2019; Römer et al., 2011; Van Waart et al., 2015). One of the intriguing aspects of design jams are that there are no correct or incorrect answers throughout the development process. Its adaptability facilitates use in a wide variety of disciplines, including engineering, healthcare, and sociology research.

To organize Design Jams, LEGO Serious Play (LSP) was chosen to facilitate stakeholders' experiences in broadcasting their needs, which will then be transferred as knowledge and valuable information to designers (Harn & Hsiao, 2018; Kristiansen & Rasmussen, 2014). The Pahang Museum in Malaysia has been selected as context for innovative design because of its potential in developing interactive spaces and solutions for visitors, as well as its ability to expose employees to a more encompassing model of customer service provision, partly driven by future technologies.

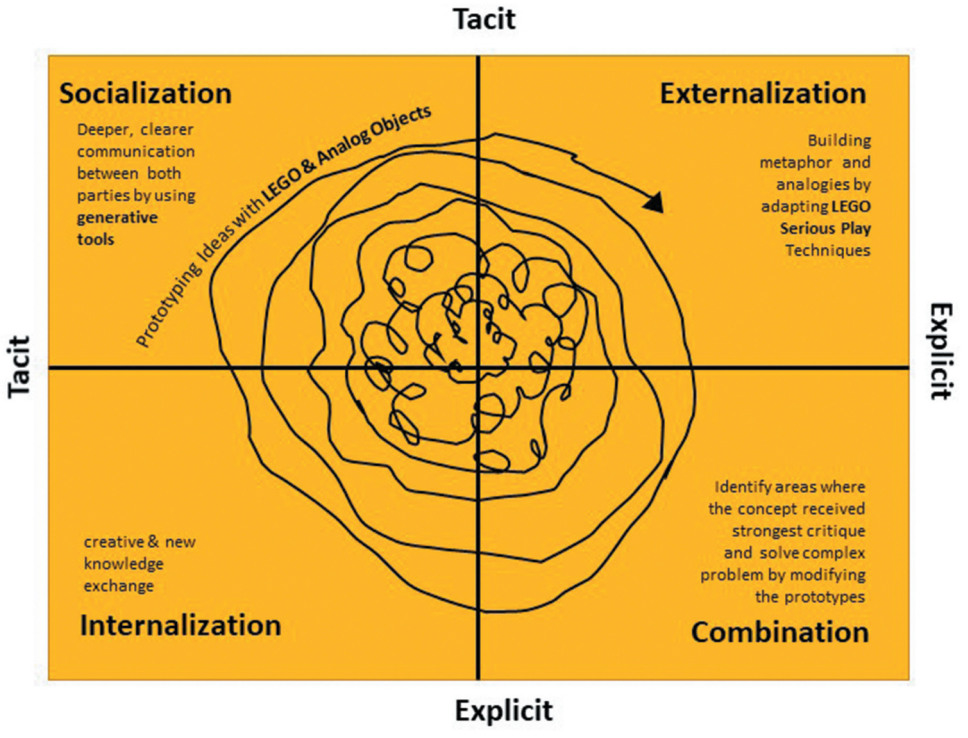


Figure 1. Positioning generative tools (LEGO and Analog objects) as a prototyping tool to enable knowledge cycle by using SECI model.

3.1. Arrangement of design jams

To explore the value and significance of LEGO and analogue objects as prototyping tools for co-design activities in anticipating innovative products, experiences and services, and as such to develop the future vision for the museum, Design Jams were conducted in 5 phases (see, Figure 2) within a 48-hour time frame, intervened by regular breaks.

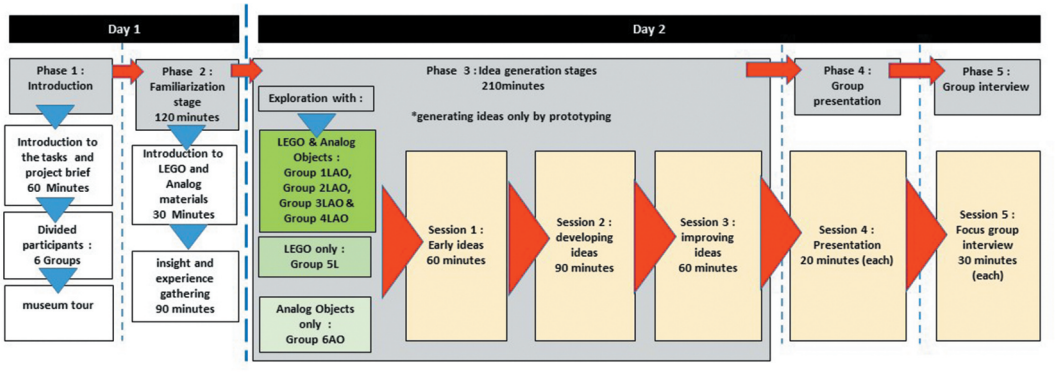


Figure 2. Tasks and arrangements for design jam.

3.2. Phase 1: Introduction to design jams & group distribution

Without prior knowledge and background of the task, 6 groups comprising of 9-10 people per group *(total 58 participants)* were invited to prototype using LEGO and Analog Objects. These participants, who were internal and external stakeholders, were briefly introduced to the research structure, aims, objectives, as well as the rules and regulations of this study. They are:

(i) Internal stakeholders: 4 designers from the museum and 22 museum staff (curators, clerk, accountant, executive managers, marketers, receptionist).
(ii) External stakeholders: 2 outside designers 32 external stakeholders (visitors, students, lecturers, general workers, external designers, supplier, copywriter, researcher, collector, volunteer).

To facilitate creativity, each of the 6 groups was allocated a participant with a professional design background. Demographically, 26 males and 32 females, aged between 22 – 45 years old with 2 – 21 years of working experience in various fields, volunteered to be part of the study. Details about the demographics of the 6 groups were provided in Table 1. The groups were given a 3-hours-tour to allow them to familiarise themselves with the aims and activities of the museum.

3.3. Phase 2: Familiarization stage with LEGO and other materials, tools and design jam concepts

A brief introduction of the co-creation assignment was conducted by the researcher, followed by familiarisation sessions on how LEGO and Analog Objects have been applied to generate ideas. After that, all the participants were instructed to mainly focus on prototyping and discussing insights from the museum tour in phase 1.

3.4. Phase 3: Idea generation & developing concept (210 minutes)

In this phase, all participants were briefed on the Design Jams format and tasked to propose new solutions for improving existing services and experiences at the Pahang Museum using only the prototyping tools provided to them. The design brief was as follows:

> *To continue to be relevant, it is critical for "Pahang Museum to attract larger audiences in new ways. While some visitors can spend the whole day exploring the museum, others will not bother to set foot inside the museum again. This is a potential problem for an institution which only depends on public funding. As museums need to be interesting and relevant for everyone, a new design experience for a FUTURE PAHANG MUSEUM needs to be proposed that meets visitor's expectations, advance educational goals, and attract new audiences."*

After explaining the design brief, the researcher announced which group will generate ideas using LEGO mix with Analog Objects, LEGO only, and Analog Objects only. The groups assigned with LEGO and Analog Objects were referred to as Group 1LAO, Group 2LAO, Group 3LAO and Group 5LAO. Meanwhile, the two control groups that generated ideas by only using LEGO were referred to as Group 5L, while only using Analog Objects was Group 6AO. Each group was assigned one facilitator who also acted as an expert to monitor the process. The facilitators' roles were to give instructions and monitor the progress of the tasks given. This phase comprised of 3 sessions:

3.4.1. Session 1: Early ideas (60 minutes)

Participants started to generate early idea using the tools given to improve and propose new solutions and directions for the "Future Museum".

Table 1. Details on the demographics data of the 6 groups

Group	Group 1LAO (10pax)					Group 2LAO (9pax)					Group 3LAO (9pax)					Group 4LAO (10pax)					Group 5 L (10pax)					Group 6AO (10pax)				
Basic Data	Total pax	Gender	Education	Age	Experiences	Total pax	Gender	Education	Age	Experiences	Total pax	Gender	Education	Age	Experiences	Total pax	Gender	Education	Age	Experiences	Total pax	Gender	Education	Age	Experiences	Total pax	Gender	Education	Age	Experiences
Designer	1	M	MA	32	8	1	M	BA	40	16	1	M	MA	31	13	1	M	MA	28	4	1	F	BA	32	8	1	F	BA	38	14
Internship Students	1	F	Dip	23	2	1	M	Dip	23	2	1	F	Dip	23	2	1	F	Dip	23	2	1	F	Dip	23	2	1	F	BA	28	4
Administrator	1	F	BA	28	5	1	F	BA	28	5	1	M	BA	28	5	1	M	BA	28	5	1	M	BA	28	5	1	M	BA	29	5
Marketing	1	F	BA	27	6	1	F	BA	32	8	1	F	BA	27	4	1	F	BA	29	6	1	F	BA	30	6	1	F	BA	27	3
Lecturer	1	F	PhD	45	21	1	M	PhD	45	21	1	F	PhD	45	21	1	F	MA	45	21	1	F	PhD	45	16	1	F	PhdD	43	17
Teacher	1	F	BA	40	11	1	M	BA	28	3	1	F	BA	40	11	1	F	BA	40	11	1	F	BA	40	11	1	F	-	31	7
general	1	M	Dip	35	12	1	F	Dip	35	12	1	M	Dip	35	12	1	M	Dip	35	12	1	M	Dip	35	12	-	-	Dip	–	–
workers	1	F	BA	33	11	1	F	BA	33	11	1	M	BA	40	13	1	M	BA	33	11	1	M	BA	33	11	1	M	BA	33	11
supplier	1	F	MA	45	21	1	F	MA	36	10	–	-	-	–	–	–	-	-	–	–	–	-	-	–	–	1	F	-	45	21
Copy writer	1	M	MA	36	13	-	-	-	-	-	1	M	PhD	44	20	1	M	PhD	42	13	1	M	MA	36	13	-	-	MA	-	-
Researcher	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	M	MA	45	21	–	-	-	-	-	1	M	BA	42	15
Collector	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	M	MA	34	14	1	F		45	21
Volunteer																														

Note: * Gender: (F: Female/M: Male) * Education: (BA: Bachelor/MA: Master/Dip: Diploma)

Table 2. Tools and materials given to the participants during the activities

	LEGO	Analog Objects	Tools provided
Prototyping Materials and Tools	LEGO bricks, LEGO parts, LEGO mini figures, LEGO baseplates	Boxboard, mounting board, rope, modeling clay, sticks, decorative sticks, stickers, icecream sticks, Chenille Stems, Sponge EVA Foam, hemp rope, wire, foam, straw, sponge,	Pencil, pen and marker, Cutter, Scissors, Masking tape, Glue

3.4.2. Session 2: Developing Ideas (90 minutes)

Participants developed the previous ideas with selected materials to improve their designs.

3.4.3. Session 3: Improving Ideas (60 minutes)

Participants discussed their creations and gathered feedback by displaying their final models and preparing for the final presentations.

3.5. Phase 4: Group presentation

3.5.1. Session 4: 20 minutes presentation evaluated by the experts

After they completed the tasks, in session 4, each group presented their proposals in 15 minutes before six experts for evaluation, followed by a questions and answer session for 5 minutes.

3.6. Phase 5: Group interview

3.6.1. Session 5: 30 minutes focus group interview for each group

Six focus group interviews were conducted by the same experts/facilitators who had observed the groups earlier. The participants were asked to verbalise their thoughts, feelings, and opinions during the process.

3.7. Workspace, facilities and materials

Design Jams were conducted in separate meeting rooms, equipped with the necessary facilities for interactions and prototyping in a participatory design setting. Table 2 shows the diverse range of Analog Objects, LEGO configurations, and other tools and materials for participants to engage themselves in the co-creation process.

4. Data gathering and analysis

In this study, multiple data collection and analysis methods were adopted from Creswell and Poth (2016), Zimmerman et al. (2007), Garde and van der Voort (2016), Thompson and Borrero (2011), Deininger et al. (2017), Borgianni et al. (2020), Dickinson and Adams (2017), and Rolfe and Emmett (2020). Data collection followed the sequence from Phase 3 to 5. All sessions were video recorded for post-experimental analysis and validation. The 6 experts (see, Table 3) who acted as facilitators in the Design Jams also collected and analyzed the data with the researcher.

4.1. Data gathering and analysis during phase 3: Idea generation concept

Data collection through a direct observation method was chosen and adapted from Rolfe and Emmett (2020), Deininger et al. (2017), Dickinson and Adams (2017), and Thompson and Borrero (2011) to find out the activity sequence in task analyses. The 6 experts/facilitators collected two sets of observational data for their respective groups according to the following procedures:

Table 3. Details on experts' background

Expert Profile	Design & Creative Experience	Specialisation	Affiliation & Education
Expert1: Researcher &Educator, Design Practitioner	15 years	Expert in sustainable design and Industrial Design	University Technology MARA, Malaysia PhD
Expert 2: Researcher &Educator, Design Practitioner	22 years	Expert in design methodology, Interior Design, Event Management and Industrial Design	University Technology MARA, Malaysia PhD
Expert 3: Researcher &Educator, Consultant	27 years	Expert in Tourism Management, Event Management and Creative Industry	University Putra Malaysia, Malaysia PhD
Expert 4: Researcher, Practitioner, Museum Director	26 years	Expert in Museum Management, Event Management and Tourism Industry	Museum Pahang, Malaysia Master
Expert 5: Researcher & Educator, Design Practitioner	22 years	Expert in design methodology, design management, product design strategy and Industrial Design	Museum Pahang, Malaysia Master
Expert 6: Researcher, Practitioner, Creative Consultant	24 years	Expert in design methodology, design management and Exhibition Design	Tourism Malaysia PhD

(i) For the first data set, the expert took observation notes of stakeholder interactions in a participatory design setting throughout Session 1 (early ideas), Session 2 (developing ideas), and Session 3 (improving ideas) to understand their behavior. These notes were then descriptively analyzed, and the notes for a final summary of inference and a judgment from the participants' behavior were validated by the expert(s; Rolfe & Emmett, 2020; Thompson & Borrero, 2011). The final summaries from each group were then presented to all experts, who then reviewed the video recording of each group's activities and evaluated the summary collectively to obtain a fair final summary for data verification and validation.

(ii) For the second data set, the analysis was divided into 2 parts and the experts evaluated 8 criteria that were adapted from Deininger et al. (2017). The criteria were selected to enable future comparison of participants' prototyping behaviors to standard the practices from literature. For the first part (see, Table 4) the experts initially observed and evaluated how prototyping tools contributed to participants engagement based on the following 4 criteria and their respective action plans:

   (a) Communication: to study how participants are fully engaged with the effective exchange of ideas while prototyping
   (b) Interpersonal engagement: to define how participants equally contribute in developing ideas and resolve conflicts through open discussions.
   (c) Group decision and planning: to measure the decision-making progress, which were made by the groups.
   (d) Roles and distributions: to measure how the group establishes clear and formal roles for each member and distributes the workload equally.

Table 4. Sample of experts' evaluation form for section 1 phase 3, how LEGO and Analogue Objects as prototyping tools contribute to co-creation activities.

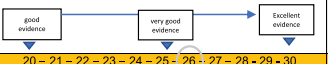
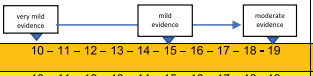
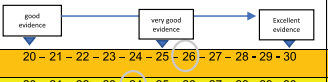
Topic (Weight)	0–9 little or no evidence of the behaviour	10–19 some evidence of an intermediate behaviour	20–30 evidence that behaviour aligned with best practice	Total Marks
1. Communication : Everyone is fully engaged with effective exchange of ideas.	The group is only engaged with encouragement or not all members are engaged. Ideas are not exchanged effectively. 	The group is engaged but can be distracted. Ideas are exchanged with encouragement. 	Everyone is engaged most of the time. The exchange of ideas is effective most of the time. 	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	25
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	24
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	15
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	10
2. Interpersonal Engagement : Members of the group share respect for each other. All members of the group feel free to ask questions and contribute. Conflicts are resolved with open dialogue and compromise.	The group atmosphere is competitive and/or individualistic. Conflicts that arise are not dealt with or cannot be resolved and/or there are no effective group interactions. 	There is a general atmosphere of respect for group members, but some members of the group do not feel free to ask questions and contribute. Members are generally able to resolve conflicts through open discussion with outside assistance 	There is a general atmosphere of respect for all group members. The majority of group members feel free to ask questions and contribute. Members are generally able to resolve conflicts through open discussion. 	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	22
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	9
3. Group Decision & Planning : A clear procedure for making decisions is formally established by the group.	There is no decision making process, decisions are made by individuals. 	A procedure for making decisions is established by the group, but it is not clear and/or it focuses on individuals. 	A clear procedure for making decisions is informally established by the group. 	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	24
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	24
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	9
4. Roles & Distribution : The group establishes and documents clear and formal roles for each member and distributes the workload equally.	The group does not establish roles for each member and/or the workload is unequally distributed. 	The group establishes informal roles for each member. The workload could be distributed more equally. 	The group establishes clear and formal roles for each member and distributes the workload equally. 	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	24
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	22
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	16
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	16
Comments : Group involved with LEGO and analogue objects perform well in this task, they did communicate effectively with each other.				

Table 5. Sample of experts' evaluation form for section 2 phase 3, how participants used LEGO and Analogue Objects as prototyping tools in co-creation activities

Topic (Weight)	0–9 little or no evidence of the behaviour	10–19 some evidence of an intermediate behaviour	20–30 evidence that behaviour aligned with best practice	Total Marks
Prototypes are used to engage with stakeholders	No evidence of stakeholders' engagement from the use of prototypes. (extremely poor evidence / very poor evidence / poor)	Stakeholders' engagement from the use of prototypes is present and serves to show improvement and to acquire general feedback. (very mild evidence / mild evidence / moderate evidence)	Stakeholders' engagement from the use of prototypes is evident as intentionally done to acquire specific feedback. (good evidence / very good evidence / Excellent evidence)	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28.5
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	22
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	15
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	12
Prototypes are used to communicate ideas to team members and stakeholders.	No evidence of using prototype(s) to communicate design concepts or ideas. (extremely poor evidence / very poor evidence / poor)	Unintentionally or accidentally use prototype(s) to communicate with teammates or stakeholders. (very mild evidence / mild evidence / moderate evidence)	Prototype(s) intentionally used to communicate, with teammates and stakeholders. (good evidence / very good evidence / Excellent evidence)	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28.5
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	22
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	12
Use prototyping iteratively and develop increasingly refined prototypes.	No evidence of refinement or integration of additional knowledge into prototype(s). (extremely poor evidence / very poor evidence / poor)	Some refinements and integration of knowledge into prototype(s) is evident. (very mild evidence / mild evidence / moderate evidence)	Clear evidence of major refinements and integration of knowledge acquired from earlier prototype(s). (good evidence / very good evidence / Excellent evidence)	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	24.5
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	12
Multiple concepts are prototyped in parallel to help with the selection of the most promising approach	None or only one prototype at a time was created. (extremely poor evidence / very poor evidence / poor)	Several prototypes were created but not in parallel, and do not facilitate in the selection of the best approach. (very mild evidence / mild evidence / moderate evidence)	Several prototypes which are in parallel and facilitate the selection of the best approach was created. (good evidence / very good evidence / Excellent evidence)	
Group 1LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	28
Group 2LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	26
Group 3LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	22.5
Group 4LAO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	18
Group 5L	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	16
Group 6AO	1 – 2 – 3 – 4 – 5 – 6 – 7 - 8 - 9	10 – 11 – 12 – 13 – 14 – 15 – 16 – 17 – 18 - 19	20 – 21 – 22 – 23 – 24 – 25 – 26 – 27 – 28 - 29 - 30	16.5
Comments :				

(For the second part, the experts evaluated how participants used prototypes in the co-creation process and what is required to meet the following criteria (see, Table 5):

(a) engagement with stakeholders: to study how prototypes are used to engage with stakeholders
(b) communication of ideas: to measure how prototypes are used to communicate ideas between team members and stakeholders
(c) iterative idea development: how do participants develop prototypes iteratively

(d) proposing multiple concepts: how do participants develop multiple concepts in parallel to help with the selection of the most promising approaches.

Referring to Tables 4 and 5 the experts rated the groups using evaluation rubrics adapted from Deininger et al. (2017) based on the 3 metric analysis on evidence of participants behaviour. To be able to measure the variables accurately, a scale for each criteria have been developed in consultation with experts to distinguish between low, moderate, and high levels of originality and necessary (Dickinson & Adams, 2017). As a result, a nine-level Likert scale was developed to evaluate the uniqueness of viable ideas. The evaluation rubrics were on a scale of 0 to 30 marks, with 0 to 9 marks representing poor behaviour during the presentation (0-3: extremely poor evidence; 4-6: very poor evidence; 7-9: poor evidence), 10 to 19 marks representing an intermediate application of the expected best practice (10-13: very mild evidence; 14-16 mild evidence; 17-19 moderate evidence) and finally, 20 to 30 marks providing evidence that this group followed best practices in presenting (20-23: good evidence; 24-26: very good evidence; 27-30: excellent evidence).

To obtain equivalent marks for this second data set, the other experts who were not appointed as facilitators of the assigned group also needed to give marks based on the evaluation rubrics by observing the recorded videos when evaluating the data of the first set. Lastly, the researcher compiled all the marks to average the final marks for complete validation.

4.2. Data gathering and analysis during Phase 4: Presentation on the final output

In this fourth phase, data were collected from the group presentations and the final display prototypes. The 6 experts were tasked to assess the participants' ideas while they were delivering their presentations of the final concept. Complementary, the two data sets, 'quality of ideas' and 'quantity of ideas', were collected during this phase. For the first data set, the experts evaluated the quality of ideas and how participants prototyped their design solutions using the assigned tools. The criteria were selected from a list of codes that described how novice designers used prototypes to connect with stakeholders (Deininger et al., 2017). The selection criteria were:

(i) overall appearance: to assess participants' efforts in creating the model while paying close attention to aesthetic values and ensuring that the model is assembled according high standards
(ii) design problem and boundaries: to assess participants' clear and comprehensive understandings of design goals and constraints
(iii) design concepts: to evaluate how clearly participants' concepts were presented and elaborated, and how effective the selection process was
(iv) use of assigned tools: to assess participants' mastery of available tools and resources through demonstrations of craftsmanship
(v) innovation: to evaluate participants' optimum development of the proposed new technology and innovative ideas
(vi) final design: to determine if participants were successful in meeting the objectives as communicated in the design briefs.

Next, the experts were asked to quantitatively evaluate the ideas on a 3-point Likert scale (1 = Poor; 2 = Good; 3 = Excellent). The application of a 3-point Likert scale was sufficient to search for 'agreeable' and 'disagreeable' polar points as well as a neutral reference point (refer table 6).

Concerning the second data set, the experts assessed the quantity and quality of ideas to find out whether prototyping with LEGO and Analog objects increased participant's abilities to generate ideas. The ideas were assessed according to how many new ideas met the objectives of the project brief. These ideas encapsulated metaphors mutually consented to by all experts, following these two criteria; (i) clarity of form and shape, and (ii) detailing and visual appearance.

Table 6. Sample of experts' evaluation form for section 1 for phase 4, scoring for final output of idea generation

Topic (Weight)	(1) Poor	(2) Good	(3) Excellent	Group 1LAO	Group 2LAO	Group 3LAO	Group 4LAO	Group 5L	Group 6AO
Overall Appearance	Inadequately built model, lacks effort and concerns on aesthetic values with disorganized components.	Proper installation of models with a satisfactory evident of effort and concerns on Aesthetic values, however, there is a an obvious need of a better trimmed or well-arranged components. 	The assembly of the model is performed to an excellent standard. There was a clear evident effort in making the model with a comprehensive concern on the aesthetics values. 	**3 : Excellent**	**3 : Excellent**	**3 : Excellent**	**3 : Excellent**	**2 : Good**	**2 : Good**
Design Problem and Boundaries	Inadequate understanding of the problem with major defects impair the quality.	An adequately sound understanding of the problem and constraints yet with does not significantly damage to the quality. 	Unobstructed and extensive understanding of design goals and limitations. 	**3 : Excellent**	**3 : Excellent**	**3 : Excellent**	**2 : Good**	**2 : Good**	**2 : Good**
Design Concepts	Very limited presentation of concepts, elaboration was vague, selection process was limited 	A logical presentation of concepts, elaboration was decent, selection process was sensible 	Very well presentation of concepts, elaboration was clear and comprehensive, selection process was sensible 	**3 : Excellent**	**3 : Excellent**	**3 : Excellent**	**2 : Good**	**1 : Poor**	**1 : Poor**
Used of Assigned Tools	Limited use of tools and resources 	Satisfactory use of tools and resources 	Highly proficient use of available tools and resources with displays of craftsmanship 	**3 : Excellent**	**3 : Excellent**	**3 : Excellent**	**2 : Good**	**2 : Good**	**1 : Poor**
Innovation	No development on proposed new technology. No evident of innovation. 	Minimal development on proposed new technology. Moderately Innovative. 	Optimal development on proposed new technology. Highly innovative. 	**3 : Excellent**	**3 : Excellent**	**3 : Excellent**	**2 : Good**	**2 : Good**	**1 : Poor**
Final Design	Not able to achieve the brief objectives of the design.	Able to meet the brief objectives of the design. 	Successfully achieve the brief objectives of the design. 	**3 : Excellent**	**3 : Excellent**	**3 : Excellent**	**2 : Good**	**2 : Good**	**2 : Good**
Total Output Indicator by expert				**Excellent**	**Excellent**	**Excellent**	**Good**	**Good**	**Poor**

4.3. Data gathering and analysis during phase 5: Focus group interview

The questions addressed to the respondents focused on (i) participants' satisfaction: how satisfied were they with the whole design process? (ii) prototyping challenges: what were the problems they encountered while generating and prototyping ideas with the tools given, and (iii) opinion on the process: what expectations and preconceptions did the participants have regarding this design process? The participants were specifically asked to reflect critically on their processes, thoughts, and ideas when answering these questions. The interview data were transcribed and evaluated by the same 6 experts. They used thematic analysis to go through the scripts several times and jointly develop the coding and themes with the researcher. The researcher then organized the findings according to these codes and themes using Atlas Ti software.

5. Results

This section reports on the results of the Design Jams, where participants were observed while prototyping with LEGO and Analog objects during the idea generation stages, presentation sessions, and focus group interviews. Results were discussed according to the process from phase 3 til 5 on participants' behavior, tools-use, design resolutions, and opinions of what has been delivered during the design jams and idea generation sessions.

5.1. Results from direct observation during phase 3: idea generation sessions

Results from observing participants' co-creation activities using LEGO and Analog Objects were discussed according to the summarized observational analyses of inference and a judgment from the participants' behaviors during sessions 1 until 3:

5.1.1. Group 1LAO: generate ideas with LEGO and analog objects

In the early stage (session 1), participants explored ideas more holistically by emphasizing existing services and user experiences at the museum. Building on their past experiences, these participants demonstrated a significant implicit understanding of these services and user issues and therefore did not feel the need to explicitly elaborate on them at this stage. For this group, more abrupt transitions from holistic to the concrete development of ideas (session 2) can be seen during the prototyping development stage. Moreover, a significant increase in detailed constructions (session 3) and prototyping activities showed that more iterative and reflective thinking took place when generating new design solutions. This indicates that participants and professional designers were comfortable when using LEGO and Analog Objects as prototyping tools in the problem-solving and idea generation activities.

5.1.2. Group 2LAO: generate ideas with LEGO and analog objects

This group showed greater momentum in exploring ideas (session 1) and solutions by constructing and interacting with modeling materials. LEGO and Analog Objects were also used to prototype problem solutions, develop new ideas (session 2), and initiate fruitful discussions among the participants to complement these ideas and solutions through contextual experience building (session 3). Moreover, participants also came up with ideas and solutions by building metaphorical models from LEGO. From these complete representations, it can be concluded that LEGO and Analog Objects are flexible prototyping tools that facilitate co-creation activities and broaden the creative space.

5.1.3. Group 3LAO: generate ideas with LEGO and analog objects

This group created ideas with multiple design solutions when using LEGO and Analog Objects as prototypes in the early idea stages (session 1). Through clear and structured problem-solving

processes (session 2), this group emphasized prototyping new experiences, ideas, and detailing concept solutions using LEGO and Analog Objects (session 3). They focussed on constructing separate components and modules from different materials to integrate them into a variety of holistic design solutions.

5.1.4. Group 4LAO: generate ideas with LEGO and analog objects

During the early ideation stage (session 1), this group produced rough and basic ideas mainly by exploring with LEGO. The focus was less on the detailing. The exploration of ideas using other materials was very limited because participants neither possessed a comprehensive knowledge of the project nor were they interested. They only focused on geometric ideas using LEGO (session 2) and were not able to detail their ideas using other visualization materials. Moreover, as participants became more involved in the prototyping activities (session 3), they were still not using much alternative materials because they were accustomed to LEGO which they found sufficiently flexible and of an acceptable resolution to represent and communicate the actual design intent.

5.1.5. Group 5 L: generate ideas with LEGO only

This control group developed ideas by only using LEGO while generating ideas (session 1) and discussing the target concepts of new experiences they wanted to propose for the future museum. The participants were eager to perform the given task but progressed slowly in the development stages (session 2). They explored lesser ideas and mainly focused on developing geometric shapes. But surprisingly, they came up with multiple solutions (session 3) through problem finding and group discussions while prototyping the ideas

5.1.6. Group 6AO: generate ideas with analog objects only

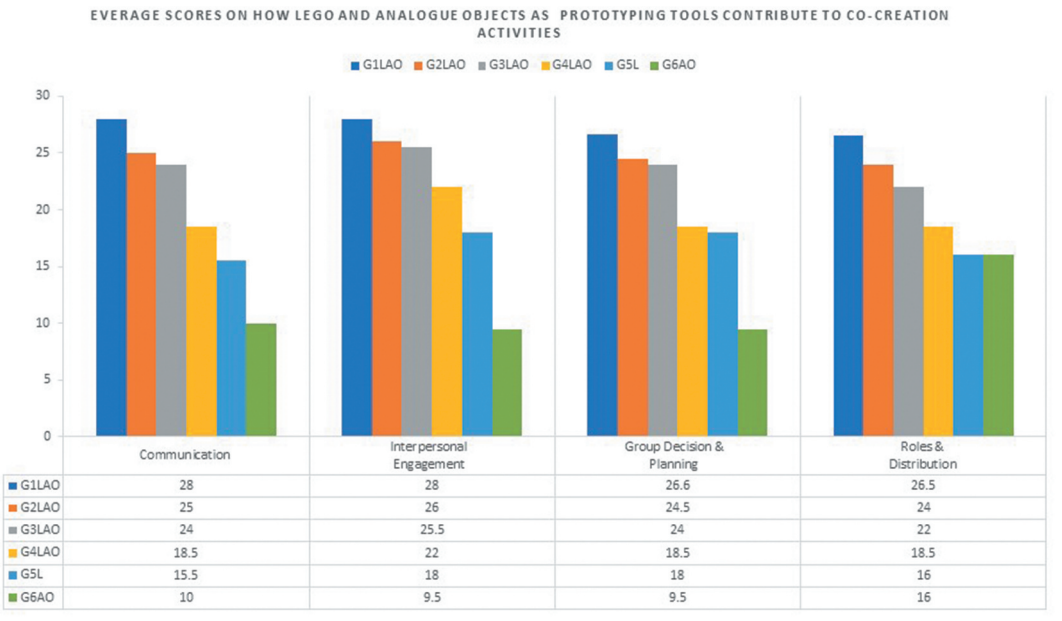
Similar to Group 5 L, this group initially showed enthusiasm and energy when generating early ideas (session 1). However, when developing their ideas (session 2), group members communicated and engaged lesser with one another during prototyping activities because all were too focused on developing their limited number of ideas with familiar materials.

5.2. Overall findings for direct observation

In the early ideation stages, all groups explored a significant number of ideas by emphasizing on existing problems and users' experiences at the museum. During this phase, the breakdown of prototyping tools assigned to the group did not impact their idea generation abilities but instead helped them speculate how their design would perform. However, this explorative behavior was only pursued by the groups that prototyped with LEGO and Analog Objects (LAO 1 – LAO 4). These groups extended their explorative behavior into the idea development stage to confirm new design directions and anticipate innovative design solutions. In the consecutive development stages, more abrupt transitions from holistic to concrete development of ideas were observed. The groups focused more on developing detailed constructions and reflected more on problem solutions as well as user's insights and needs. A majority of the participants exchanged ideas during the development stage through reflective conversations with one another and the prototypes they were interacting with.

5.3. Findings on how LEGO and analogue objects contributed to co-creation activities

Figure 3, shows how six different groups were assessed on how the prototypes contributes to co-creation activities using four different metrics. These metrics addressed the flow of 'communication', excellence of 'interpersonal engagement', clarity in 'group decision-making and planning', and finally, the clear separation and equal 'distribution of group roles'. Out of all the six groups assessed, Group 1LAO obtained the best overall results, followed by Groups 2LAO and 3LAO.



	Communication	Interpersonal Engagement	Group Decision & Planning	Roles & Distribution
G1LAO	28	28	26.6	26.5
G2LAO	25	26	24.5	24
G3LAO	24	25.5	24	22
G4LAO	18.5	22	18.5	18.5
G5L	15.5	18	18	16
G6AO	10	9.5	9.5	16

Figure 3. Average score on how prototyping tools contribute to co-creation activities.

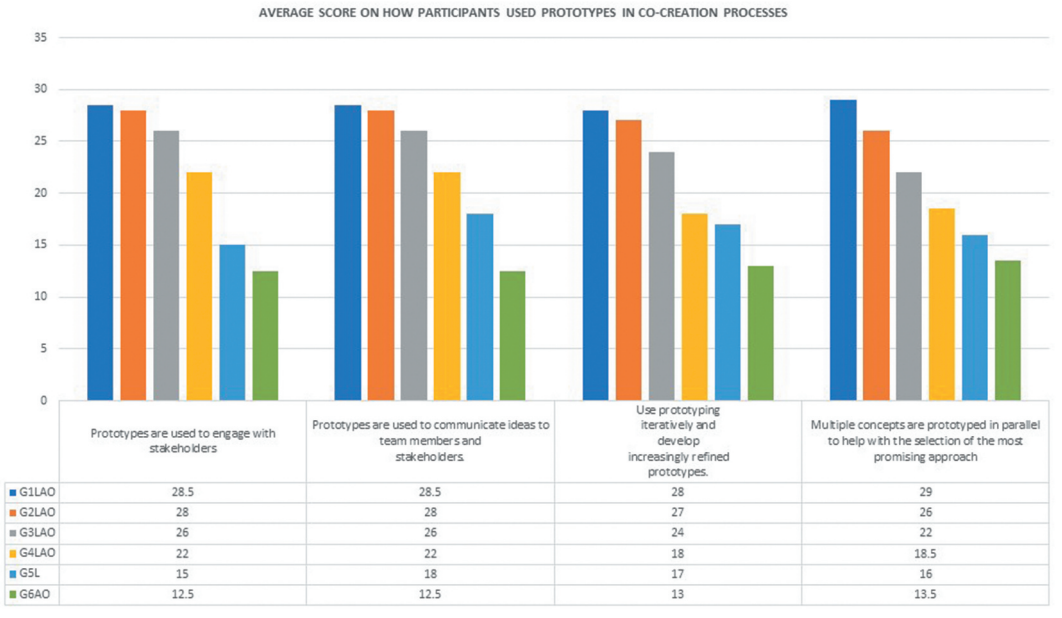
Group 4LAO performed at a slightly above-average level. In contrast, Group 5 L demonstrated an intermediate grasp of the expected best behavior during the presentation, obtaining 67 marks and placing themselves consistently in the intermediate tier on all metrics. However, Group 6AO performed poorly, placing themselves in the bottom tier of 'interpersonal engagement' and group 'decision-making & planning'. This indicates that the groups assigned with LEGO and Analog Objects for prototyping performed better in representing, evaluating, and communicating design ideas in co-creation processes.

5.4. Findings on how participants used LEGO and analogue objects during co-creation activities

Figure 4 illustrates the behavior of six different groups when developing prototypes. All the groups were assessed by measuring the prototyping metrics for 'stakeholder liaising', 'communication of ideas' to team members and fellow stakeholders, the 'improvement of prototypes', and the process of 'creating multiple prototypes in lieu of choosing the method with the highest potential'. Group 1LAO posted the highest total marks of the six groups participating in the assessment, followed by Groups 2LAO, 3LAO and 4LAO, which performed similarly well but slightly lagged in developing multiple parallel prototypes. Groups 5 L and 6AO were found to have presented and developed their prototypes at an intermediate level compared to the other groups, with both groups posting 67 and 52 marks respectively and scoring 12–18 marks for each assessed metric. This shows that LEGO and Analog Objects together are effective tools for collaborative design thinking, ideation, and communication in a participative environment.

5.5. Findings from final output of idea generation during phase 4: presentation session

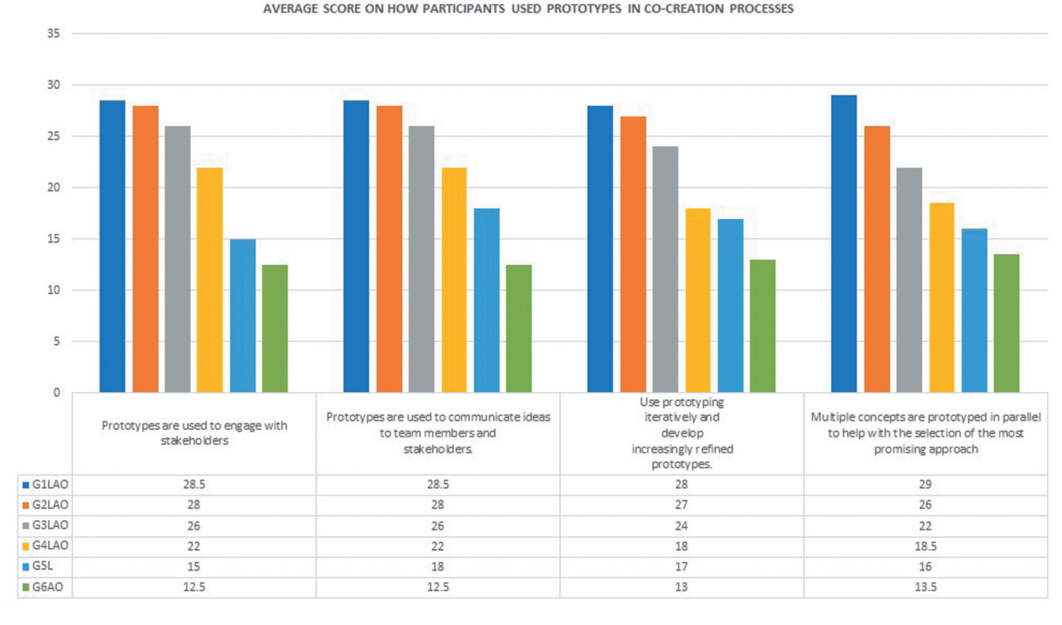
Results from Figure 5 indicated that Groups 1LAO, 2LAO and 3LAO performed excellently on all criteria. Although Group 4LAO showed a very good 'overall performance', but they did not manage to formulate design problems and boundary setting, as well as the developing design concepts, using



	Prototypes are used to engage with stakeholders	Prototypes are used to communicate ideas to team members and stakeholders.	Use prototyping iteratively and develop increasingly refined prototypes.	Multiple concepts are prototyped in parallel to help with the selection of the most promising approach
G1LAO	28.5	28.5	28	29
G2LAO	28	28	27	26
G3LAO	26	26	24	22
G4LAO	22	22	18	18.5
G5L	15	18	17	16
G6AO	12.5	12.5	13	13.5

Figure 4. average score on how participants used prototypes in co-creation processes

assigned tools to achieve the intended innovation level in the final project. Groups 5 L and 6AO performed poorly on using 'assigned tools' and 'innovation'. However, they displayed good performance in aesthetically presenting a final design, understanding the design problem and setting boundaries. This shows that jointly prototyping with LEGO and Analog Objects is effective, whereas using LEGO or Analogue Objects alone limits creativity and innovation.



	Prototypes are used to engage with stakeholders	Prototypes are used to communicate ideas to team members and stakeholders.	Use prototyping iteratively and develop increasingly refined prototypes.	Multiple concepts are prototyped in parallel to help with the selection of the most promising approach
G1LAO	28.5	28.5	28	29
G2LAO	28	28	27	26
G3LAO	26	26	24	22
G4LAO	22	22	18	18.5
G5L	15	18	17	16
G6AO	12.5	12.5	13	13.5

Figure 5. Idea generation scores for each group.

When comparing the two groups tasked only with one tool to their disposition, the group assigned to prototype with LEGO and analogue objects produced more ideas, concepts, and detailed constructions. They were able to better forecast new design directions of ideas that met the objectives of the project brief and were more constructive when exploring with modeling materials (see, Table 7). The ease of using both tools is evident in the quality and resolution of their final prototypes.

5.6. Findings from in-depth group interviews during Phase 5: Focus group interview sessions

Groups 1LAO, 2LAO, and 3LAO showed an equal preference for LEGO and analogue objects as prototyping tools compared to Group 4LAO, which focussed more on LEGO while using only a minimal amount of analogue objects for prototyping. However, all groups were convinced that prototyping with LEGO and analogue objects at the same time enhanced exploration and metaphorical representation. The participants also emphasized the use of LEGO human figurines as a scaled reference for their design outputs. In response to the experts' questions on why Group 4LAO participants prototyped using more LEGO elements instead of analogue objects, they answered;

> *" . . . in first instance, when we were introduced to LEGO and other materials to prototype, we immediately picked LEGO because there was no need for any additional tools to build something. We produced and developed more ideas faster than combined with other materials. When using other materials, we encountered so many limitations that we needed additional tools to complete our prototypes, which took longer time . . . ."*

> *" . . . I am more confident to prototype with LEGO only . . . I felt stressed when I'm not getting the right ideas when I started to combine LEGO with other materials, it seems it was not the right combination to develop ideas . . . I'm stuck for few minutes before I stopped combining both materials . . . ."*

On the other hand, when the experts asked Groups 1LAO, 2LAO and 3LAO that equally prototyped with LEGO and analogue objects, they mentioned that;

> *" . . . with LEGO making organic shapes was quite difficult and time-consuming. Needs a very skilled person to represent good ideas."*

> *" . . . the combination of both materials to prototype was helping me to generate many ideas. Starting with LEGO, we can explore and experiment indirectly and improve our design on the spot . . . then we can easily develop and combine our ideas with other materials . . . ."*

> *" . . . While combining materials, I can easily translate my intentions into tangible ideas . . ., and further develop them. This means that I want to construct my initial ideas with LEGO and then expand them using other materials."*

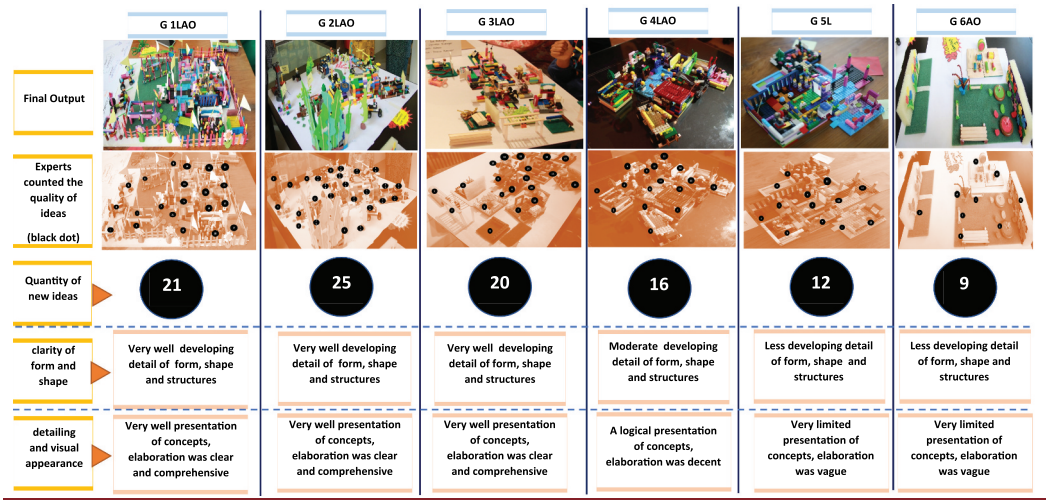
During the focus group interview session with Group 5 L, most participants were excited to start generating ideas using LEGO. However, when developing ideas, they faced several limitations as described below:

> *" . . . I like to prototype using LEGO. We did not need any supporting tools to quickly make combinations and deformations. But at a certain point, I felt the limitations of LEGO. When I wanted to prototype more ideas, my mind was fixated on geometric shapes and boxy things . . . ."*

> *" . . . my first time playing with LEGO was excited, but I had some issues on how to visualise my ideas using LEGO . . . At first, I felt it is ridiculous . . ., but while engaging with the materials, it creates more fun than I expected,"*

The other control group, Group 6AO shared the same excitement as group 5 L when generating early-stage ideas with the materials given. However, they encountered time limitations to further develop these ideas by using analogue objects because they also needed additional support tools:

Table 7. Number of ideas produced by each group



> *" . . . I need to used glue, masking tape to stick the given material, and it took much longer time and sometimes I became bored while waiting for the material to dry. I had to make another idea while waiting to develop the first idea, and it blocked my creativity . . . ."*

> *" . . . I create my ideas using plasticine, and it took longer time than expected to reshape the form, and we iteratively changed the form because we were not satisfied with the shape, as the materials could easily be changed to what we wanted . . . and we wasted our time there, too much focus on creating early ideas. No time to develop the concept . . . ."*

When participants were asked about the advantages of LEGO and analogue objects, the majority agreed that analogue objects are more suited for expressing realism in prototyping by accommodating organic and complex shapes. By prototyping with LEGO and Analog objects at the same time, more versatile and interesting design solutions and directions were produced, compared to being limited to one medium, as shown in Figure 6. Referenced to the participants' prevailing

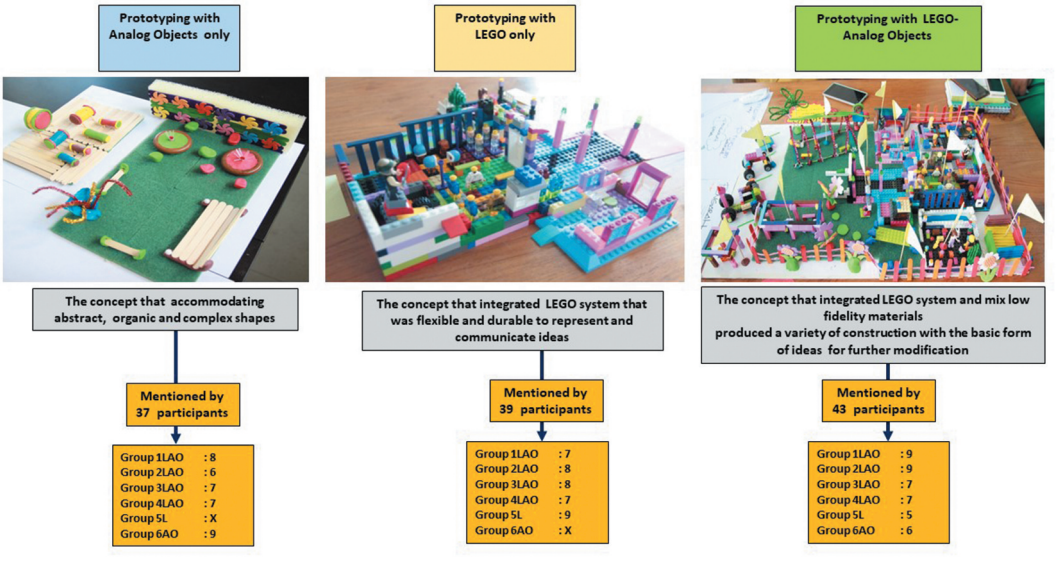
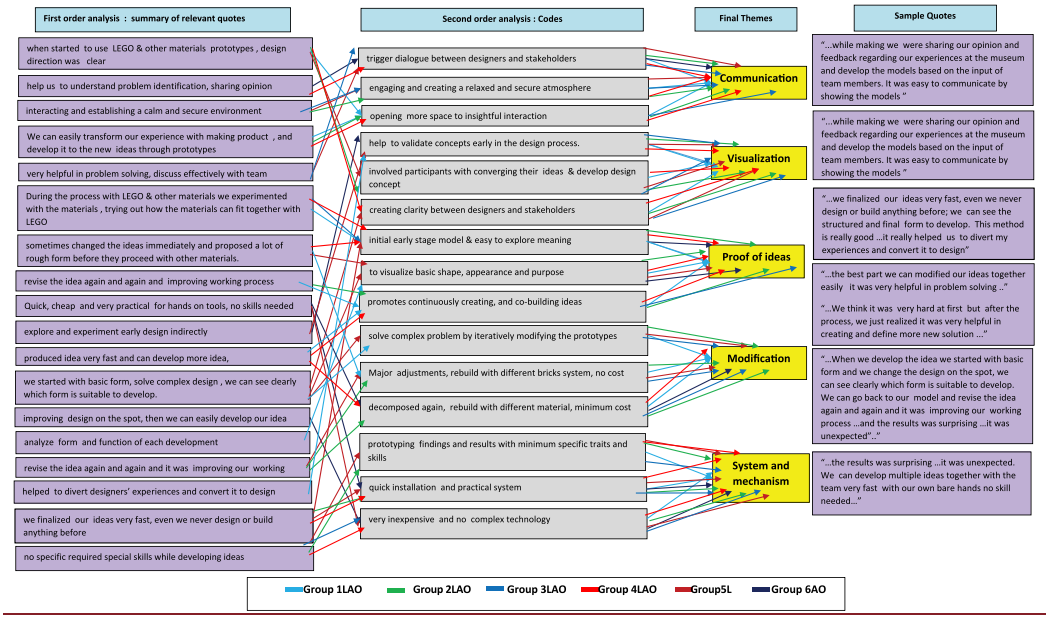


Figure 6. Comparing prototyping with LEGO only, Analog Objects only and LEGO-Analog Objects

Table 8. The coding analysis from the focus group interview.



design behaviors, attitudes, and mindsets, each of the materials showed its strengths and weaknesses in terms of how they were applied and how they contributed to each stage of the design process. Notably, all participants appreciated the contribution of LEGO and Analog Objects as prototyping tools for the design development process because it accommodated divergent and convergent exploration of ideas, as well as more accurate evaluation of the design through interactions with the prototype/model.

Keywords, derived from literature reviews and the analysis of transcripts from the focus group interviews led to the emergence and deliberate organization of hierarchical clusters and themes. The creation of themes from both perspectives ensured that multiple meanings and interchangeable descriptions of the same term were considered. Table 8 illustrates how the themes emerged and were created.

Table 9 highlights the sequential order of the analysis as well as the emerging themes based on the reduced data. It maps the benefits of using LEGO and Analog Objects, combined or separately, when prototyping and co-creating, involving designers, non-designers, end-users, and other stakeholders. A majority of the respondents agreed that the combination of LEGO and analogue objects facilitated prototyping activities by focussing on 5 emerging themes; (i) communication, (ii) visualization, (iii) proof of ideas, (iv) modification, and (v) system and mechanism. The element of 'playfulness' by using LEGO and analogue objects encouraged participation and improved 'communication' between designer-user-stakeholder. However, it requires participants to sort out their individual's ideas and objectives in advance before embarking on group work. Moreover, because of the need for more precise representations, using LEGO and Analog Objects simultaneously may enhance creativity and encourage designers-user-stakeholders to jointly develop ideas (Peters & Ahmadpour, 2020), (Isa & Liem, 2020) and (Van Waart et al., 2015). Furthermore, as 'Proof of ideas', LEGO and Analog Objects are also suited for defining innovative design solutions, because they are compatible and easily interchangeable when developing initial concepts and ideas without much needed skills and at minimal costs.

Table 9. Summarizes of the interview analysis on participants reflections of the process.

How LEGO & Analog Objects as prototyping benefited in	Assigned tools	Group 1LAO, Group 2LAO, Group 3LAO, Group 4LAO: LEGO & Analog Object	Group 5L: LEGO	Group 6AO: Analog Object
	Communication	trigger dialogue between designers and stakeholders engaging and creating a relaxed and secure atmosphere opening more space to insightful interaction	trigger dialogue between designers and stakeholders engaging and creating a relaxed and secure atmosphere	trigger dialogue between designers and stakeholders
	Visualization	help to validate concepts early in the design process. involved participants with converging their ideas & develop design concept creating clarity between designers and stakeholders	help to validate concepts early in the design process. involved participants with converging their ideas & develop design concept creating clarity between designers and stakeholders	help to validate concepts early in the design process.
	Proof of ideas	initial early stage model & easy to explore meaning to visualize basic shape, appearance and purpose promotes continuously creating, and co-building ideas	initial early stage model & easy to explore meaning to visualize basic shape, appearance and purpose	initial early stage model & easy to explore meaning to visualize basic shape, appearance and purpose
	Modification	solve complex problem by iteratively modifying the prototypes Major adjustments, rebuild with different bricks system, no cost decomposed again, rebuild with different material, minimum cost	solve complex problem by iteratively modifying the prototypes Major adjustments, rebuild with different bricks system, no cost	decomposed again, rebuild with different material, minimum cost
	System and mechanism	prototyping findings and results with minimum specific traits and skills quick installation and practical system very inexpensive and no complex technology	prototyping findings and results with minimum specific traits and skills quick installation and practical system very inexpensive and no complex technology	quick installation and practical system very inexpensive and no complex technology

6. Discussion

The combined use of LEGO and Analog Objects resulted in effective prototyping when transforming insights, knowledge, and ideas into convincing design directions in the early product planning stages. To understand the reasons why, the following research questions are answered below:

RQ 1: What are the advantages and disadvantages of combining LEGO with analogue objects in co-creation activities?

Combining the easy-to assemble qualities of LEGO with flexible but sometimes basic analogue objects kept participants motivated to refine their ideas to iteratively create and evaluate better solutions while introducing new meanings and functionalities, as shown in Figure 7.

The simultaneous application of LEGO and Analog Objects in low-fidelity prototyping provided designers-stakeholders with quick and proficient feedback of their designs, which enabled them to work in a more flexible and adaptive manner to comply with realistic project requirements and

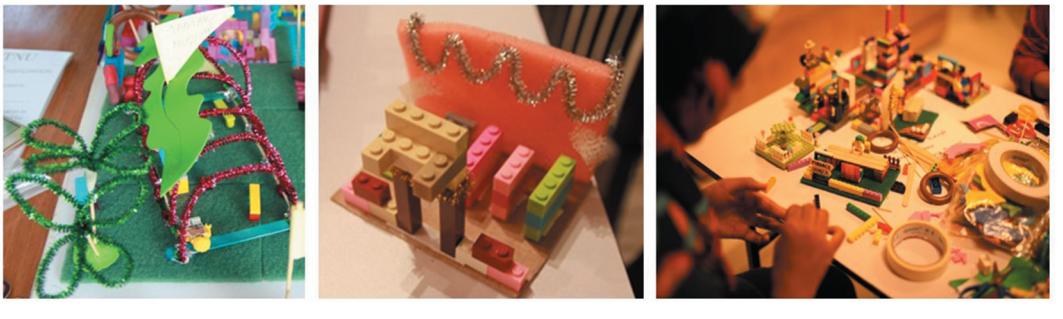


Figure 7. Rough and incomplete appearance of ideas.

deadlines. LEGO on its own can be iterated quickly without the need to deform its elements due to its versatile construction and mechanism. When prototyping using LEGO, it can be seen that the participants were excited to freely and immediately create ideas without thinking on how to manipulate the tools. LEGO's ubiquitous ability to spark imagination generated multiple ideas for discussion. Although the combination of LEGO and Analog Objects are the focal point of discussion in this article, each mode of representation also has their own merits with respect to design and innovative contributions. On its own, Analog Objects are easily moldable and transformable when generating multiple and challenging free-form shapes, as well as easily represented in a rough and incomplete format due to the characteristics of the material. Moreover, they are low-cost and effective in fine-tuning and developing detail explorations.

When anticipating future needs and products, LEGO and Analogue objects facilitated in developing longer-term design directions because it stimulated participants to think more critically through a process of experimentation, reflection and decision making. Moreover, it helped them to develop a clearer understanding of design problems and set the stage for more in-depth explorations.

In the idea generation process, LEGO and Analog Objects contribute significantly in:

6.1. Improving understanding of what 'quality' means when discussing concrete artifacts

Prototyping with LEGO and Analog Objects is a complex activity, but strengthens mutual understanding between designers-user-stakeholder with common interests, needs and quality requirements. Moreover, LEGO and Analog Objects were effective prototyping tools for team and strategy building as they provided more flexibility for participation.

6.2. Comprehending new ideas while searching for new design directions through low-fidelity prototyping

Using LEGO and Analog Objects during co-creation activities in a simplified and low-fidelity manner may facilitate the extraction of essential information to ensure quality and to meet market demands. However, using of low-fidelity prototypes should be reiterated in each design stage to enable designers-user-stakeholder's to cost-effectively transform user insights, knowledge and ideas into new design directions for new product development.

6.3. Visualizing ideas and concepts more practically

Visualization capability of LEGO and Analog Objects helped designer-user-stakeholders to explore, evaluate, modify and validate design ideas and solutions three-dimensionally.

LEGO and Analog Objects were instrumental for establishing fundamental thoughts and directions for subsequent creative designs. Because of the completeness and 'probing' qualities of LEGO in expressing participant's feelings and experiences, participants were inclined to use more LEGO elements than analogue objects in the initial insight and discovery stages, as shown in Figure 8. By continuously prototyping with other stakeholders in the discovery and development of new ideas and concepts, LEGO and Analog Objects provided a better understanding of users' experiences, needs, and values. In the idea development stage, Analog objects and LEGO were used to the same extent to assist participants in solving problems, expressing their design ideas, and evaluating and selecting ideas for further development. During concept detailing and selection, prototyping with LEGO drastically declined. Using analogue objects comprising different materials to complement LEGO components, provided greater flexibility and higher resolutions developing and validating final concepts. Furthermore, when developing and selecting actual design directions, Analogue Objects were increasingly used with LEGO. At this stage, using a versatility of prototyping tools

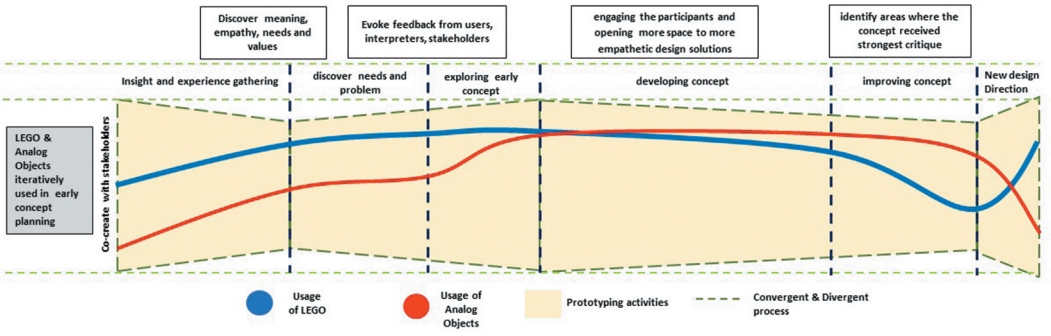


Figure 8. The comparison of approximate amount of LEGO and analog objects used in the co-creation activities to enhance the idea generation in product planning stages.

facilitated the creative process, compared to using only LEGO, which was perceived as being of too high fidelity, limiting creative explorations.

Because of LEGO's constructive limitations, elements can only be assembled in one direction due to the placement of studs and their counterpart sockets located on the opposite sides. Furthermore, the shape of LEGO elements which are intrinsic, adheres to a strict planar grid, which provides a one-directional bias in building models.

However, LEGO's standardization and high interchangeability provides sufficient flexibility and quantity in developing low and high-fidelity prototypes (Figure 9). Furthermore, due to LEGO's high configurability, quality finishings and materials, designers-user-stakeholders can easily extend low-fidelity configurations to higher ones when modeling and at the same time redesigning too complex solutions.

RQ 2: What are the insights, using LEGO and analogue objects, to facilitate collaboration and communication among designers, end-users and other stakeholders during ideation?

LEGO and Analog Objects played an important role in enhancing the effectiveness of prototypes to generate more innovative and creative ideas, specifically in the ideation and conceptualization stages, as they enabled designers to inspire and generate a greater number of designs solution. With reference to prevailing design behaviors, attitudes and mindsets among the participants, each of the

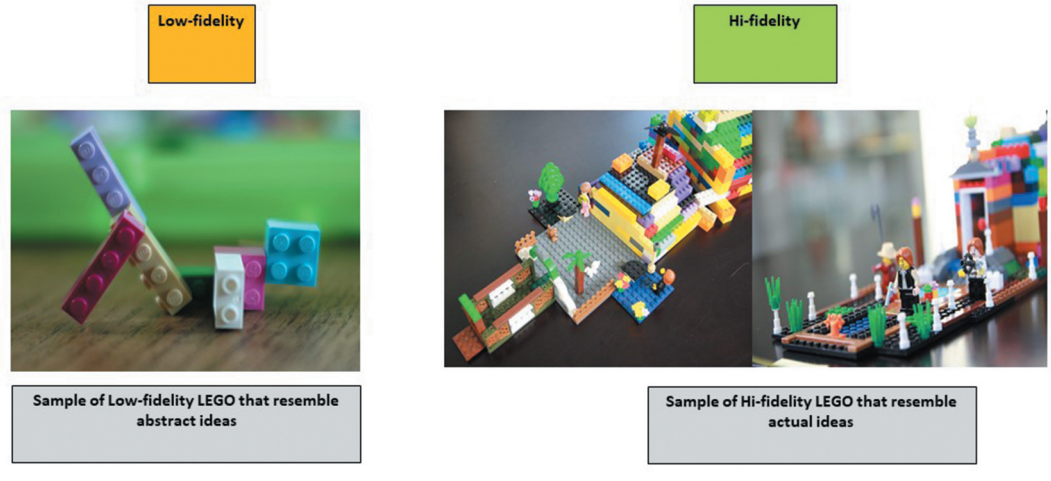


Figure 9. Comparing low-fidelity and hi-fidelity prototyping with LEGO during co-creation activities.

prototyping tools has its own strengths and weaknesses with respect to how they were applied and how they contributed to different stages in the design process. In the idea development stage, the majority of participants only explored with materials that they were familiar with, which were mainly cardboard, clay, and wooden sticks. Newly introduced materials such as balsa wood, cloth, decorative sponge, Chenille Stems, Sponge EVA Foam, quilling paper were not used so much during prototyping activities, because of the participants' lack of experience and expertise to imagine how these objects will represent and communicate the actual design intent.

Moreover, LEGO and analogue objects contributed in co-creation activities through innovative representations and forms that better engage with the expectations of different stakeholders. It also helped participants to develop common mental models, clear ambiguities, create emotions through haptic experiences, and promote coordination.

Furthermore, prototyping with LEGO bricks and Analog objects enhanced exploration and provided better engagement between designers and stakeholders to produce new design directions. It ensured that these designers and stakeholders were better guided in their creations throughout the design process. Hereby, it is important to note that co-creation activities are particularly effective in extracting stakeholders' insights with respect to anticipating future needs. According to Table 9, physical prototypes are representations to assist designers in uncovering, exploring, and anticipating the needs of stakeholders. The goal of these prototypes is not to find the full design solution or to impress stakeholders with the final product, but rather to supplement problem-solving activities. This means that LEGO and analogue objects strived to demonstrate 'proof of concept' (Table 8), particularly in early co-creation efforts. They were also more adaptable and cost-effective for communicating different design requirements and experimenting with design variations with different stakeholders. As a result, new insights about people's physiological and psychological demands, as well as unique design ideas and concept solutions, may emerge by strategically using LEGO and analogue objects as prototyping tools in the design process.

Therefore, it can be said that co-creation with LEGO and Analog Objects enables designers and other stakeholders to confirm their understanding of each other's experiential knowledge before creating and converting these to new design directions. In order for a new design direction to be effective, all information extracted from designer-stakeholders' insights and perspectives should be included and selected carefully throughout all stages of the co-creation process.

7. Conclusion and further research

In this study, the value of LEGO and Analog Objects in developing knowledge, ideas, concepts and (strategic) design directions were investigated through co-creation workshops. LEGO has proven to be very suitable for gaining user insights while keeping the design solution space broad and open for designers, users and other stakeholders to visualize and imagine as many alternatives as possible. The flexible use of LEGO and Analogue Objects in the early development stages managed to reveal design problems more accurately for more reflective, iterative, and collaborative solution-finding. Because of time constraints and design fixations, participants were initially skeptical about using LEGO in conjunction with Analog Objects to prototype design concepts and directions. However, LEGO and Analog Objects proved to be very valuable in the early development stages and should be used extensively in problem-solving, stimulating critical reflection, and opening up creative spaces.

In terms of design education, this study can be valuable for teaching design methodology, particularly with respect to reasoning and thinking. Introducing LEGO and Analog Objects in multiple configurations as prototyping tools to be applied at different stages of the co-creation process may encourage students to reflect more on what course of action is needed to achieve a certain design representation. Moreover, prototyping can be seen as a knowledge transfer and ideation activity among educators-students when sharing tacit and explicit knowledge. Furthermore, using LEGO and Analog Objects in early-stage research and design facilitates solution finding not only through analysis- synthesis but also conjecture-analysis.

Further research should focus on how to involve participants earlier in the validation of concepts, because it is more effective for product development that participants are to be included in early co-creation activities, whereas designers should emphasize on design conceptualization and detailing, capitalizing on the outcomes of these co-creation activities. Moreover, research should also explore how LEGO and Analog Objects can exploit content-rich insights and anticipate future needs, involving a more comprehensive range of stakeholders with multiple backgrounds.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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