Pós-Graduação em Ciência da Computação

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IOT4FUN: a relational model for hybrid gameplay interaction

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IoT4Fun: A Relational Model for Hybrid Gameplay Interaction

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ABSTRACT

Both toy and games industries are investing in hybrid play products. In such scenarios the user access the system using toys as input/output, thus, these products consist of playful user interfaces. Hybrid play systems are complex design artefacts since they use real and virtual information, so they present new challenges to both designers and developers. We suppose both industries could benefit with hybrid design approaches from product concepts. Our main research goal aims to develop tools and methods to assist the community in developing such interactions. Hence, we performed a systematic literature review covering related research published between 2008 and 2016. To extend our contribution, we added 120 hybrid play products from a market review. After data extraction, we managed results to propose a relational model for hybrid gameplay interaction. The model comprises several interactive aspects relating three entities: the things, environment, and people. The model allowed describing different scenarios of smart play including both active and passive technologies, that are located either in outdoor or indoor environments. Aiming to evaluate model usage, we applied it as a practical tool for designing hybrid playful systems. To achieve it, we included the model in a 16-week class to design hybrid games. We detailed model usage in the course schedule and discussed how students experienced it. Besides, we presented student's six working prototypes, including design cycles, and playtesting sessions. After class, we conducted semi-structured interviews with student's representatives. Results revealed model usefulness to describe their system setup and interface elements. According to students, model vocabulary facilitated communication among team members. Afterwards, we proposed improvements in model nomenclature based on student's feedback. Thus, to evaluate changings we applied the model in a series of three creative workshops. Workshops had 4-8 hours of duration that focused on stages of conception, ideation, and low-fidelity prototyping. Accordingly, updated model enabled participants in developing six hybrid game concepts. Finally, we summarised research contributions and recommended topics for a future methodological approach

Keywords: Playful User Interfaces. Tangible User Interfaces. Hybrid Games. Smart Toys. Human-Computer Interaction. Internet of Things.

RESUMO

As indústrias de brinquedos e jogos investem em produtos lúdicos híbridos. Nestes cenários, o usuário interage com o sistema através de brinquedos, utilizando-os tanto como entrada e saída de informação, atribuindo aos brinquedos o caráter de uma interface lúdica para o usuário. Sistemas híbridos para entretenimento são artefatos complexos por utilizarem informações reais e virtuais, apresentando novos desafios para designers, programadores e engenheiros. Adotar abordagens que considerem o design híbrido desde a conceituação dos produtos, poderá trazer benefícios tanto para a indústria de brinquedos como para a de jogos. O principal objetivo desta pesquisa é propor ferramentas para facilitar o desenvolvimento de soluções interativas no contexto de sistemas híbridos lúdicos. Uma revisão sistemática da literatura cobrindo artigos publicados entre 2008 e 2016 foi realizada e ampliada com a contribuição mercadológica que mapeou 120 produtos híbridos lúdicos. Um modelo relacional para interação com *gameplay* híbrido foi concebido e compreende aspectos interativos relacionando três entidades: as coisas, o ambiente e as pessoas. A avaliação da proposta consistiu em aplicar o modelo como ferramenta prática para a criação de novos sistemas híbridos lúdicos, em uma disciplina de curso de graduação com duração de 16 semanas. A avaliação viabilizou propor melhorias na estrutura e nomenclatura do modelo. O modelo proposto sintetiza informações complexas da interface lúdica através de um conjunto de aspectos interativos, permitindo ao usuário conceituar, planejar, e documentar os sistemas híbridos. A aplicação do modelo como uma ferramenta criativa permitiu o desenvolvimento de seis protótipos funcionais de jogos e brinquedos conectados, incluindo a modelagem conceitual de jogos híbridos e protótipos de baixa-fidelidade. Sumarizadas as contribuições, a pesquisa apontou tópicos para uma futura abordagem metodológica.

Palavras-chave: Interface de Usuário Lúdica. Interface de Usuário Tangível. Jogos Híbridos. Brinquedos Inteligentes. Interação Humano-Computador. Internet das Coisas.

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LIST OF ACRONYMS

ADHD	Attention Deficit Hyperactivity Disorder
AR	Augmented Reality
BLE	Bluetooth Low-Energy
FPS	First Person Shooter
GDD	Game Design Document
GPS	Global Positioning System
GRVM	Virtual Reality and Multimedia Research Group
GUI	Graphical User Interface
HCI	Human-Computer Interaction
HP	Health Points
IFPE	Instituto Federal de Educação, Ciência e Tecnologia de Pernambuco
I/O	Input/output
IoT	Internet of Things
IoToy	Internet of Toys
LARP	Live Action Role Playing
LED	Light Emitting Diode
NFC	Near Field Communication
QR	Quick Response
RFID	Radio Frequence Identification
RPG	Role Playing Game
SLR	Systematic Literature Review
TUI	Tangible User Interface
UFPE	Universidade Federal de Pernambuco
VR	Virtual Reality

CONTENTS

1 INTRODUCTION

Traditionally, there are two formats of play: the physical and digital. First, the physical play comprises activities either based on the interaction between people and playful artefacts, (i.e., toys and board games), or bodily interactions such as free-play and pretending play activities like ‘police vs thieves’ or hopscotch. Second, the digital play involves interaction with video games and entertainment electronics (i.e., smartphones, tablets, and portable consoles). Usually, such formats happen as a dissociated experience, however, in mid-2012, several sectors from the entertainment industries, has launched products connecting these two play formats. We name such physical-digital play experiences, as *hybrid play* interactions (see Figure 1).

Figure 1 – Users engaged in playful experiences from different modalities: the physical, digital and hybrid play.

Hybrid play products, such as connected toys, are a design trend from both toy and games industries. These are playful artefacts embedded with electronic components able to connect with other devices. Smart toys can connect with other toys, controllers, smartphones, tablets, and game consoles. Despite electronics, these products use passive technologies like computer vision techniques and conductive touchpoints. Such toys can promote different play experiences, with rigid or open rules. In these scenarios, users access the system using toys as input/output (I/O), either at outdoor or indoor environments.

Viewing toys from a human-computer interaction (HCI) perspective, these consist of playful user interfaces. Anton Nijholt (2014) defined such concept as user interfaces designed to invite users to engage in playful interactions. Hence, these systems must allow both social and physical interaction. We refer to *‘hybrid playful system’* as a collection of play activities making use of integrated digital and physical information. In that way, such system includes hybrid games, connected toys, augmented board games, multimedia applications, interactive storytelling, and open-ended play scenarios.

Hybrid games, as the term suggests, is a design format referred to games that make use of digital and physical resources. In literature, authors also refer to such games as mixed reality games, like systems using augmented and virtual reality (AR and VR) features, including the use of pervasive and contextual physical information like Global Positioning System (GPS).

According to Nijholt, such playful applications do not necessarily are entertainment applications. These can have educational goals or aim at either social or physical behaviour changes. The author claimed that designers and developers do not need to assume that, in addition to a user focusing on an application, a user has to pay attention to manipulating a mouse, using the keyboard and monitoring a screen. In this way, interface technology can emphasise more than offering means to get tasks done efficiently, but on presenting playful interaction opportunities to applications providing fun, excitement, challenges, and entertainment.

We can consider hybrid playful systems as tangible user interface (TUI) systems, since these provide a physical form to digital information. Ishii & Ullmer (1997) introduced the concept of 'Tangible Bits' as an attempt to bridge a gap between cyberspace and the physical environment by making digital information tangible. Authors claimed that traditional graphical user interfaces (GUI) failed on embracing skills that people have developed through interaction with the physical world. TUIs make use of graspable objects and ambient media, therefore, leading richer multi-sensory experiences of digital information.

The relationship among playful TUIs and games appeared on early arcade video games. In addition to pushing buttons, switches and levers, several arcades embraced bodily interaction, such as gestures and movements. In the 1970s, arcade game *Speed Race* introduced a realistic racing wheel controller imitating corresponding physical interaction. Meantime, in the '90s, Konami presented *Dance, Dance Revolution* introducing arrow pads to users engage in full-body interaction. Besides, Namco popularised the 'light gun shooter' genre with arcade game *Time Crisis*.

Later, game companies such as Nintendo and Sony (PlayStation) ported those mimetic interfaces to home consoles. Jesper Juul (2010) defined mimetic interfaces as such when players perform physical activities that mimic game actions on the screen. Related examples are *Guitar Hero* and *Wii Tennis* both from Nintendo. The author assumed that people playing mimetic interface games are often themselves a spectacle, making such games more interesting even for those who are not playing.

Playful interface games took advantage of advances in electronic components, such as small sensors, actuators, and connection protocols like Bluetooth Low Energy (BLE) and Radio Frequency Identification (RFID). Playful interface design has appropriated from other physical object’s affordances, such as a playful system able to track a ball’s speed and position, thereby, exploring interaction modalities offered by ubiquitous computing and pervasive gaming. Mark Weiser (1993) proposed a concept of ubiquitous computing as the disappearance of computing into the background of everyday objects. Afterwards, Montola et al. (2009) defined ‘ubiquitous games’ term to describe a range of games that extend and blur the spatial, temporal and social borders of the game spaces.

Initially, pervasive gaming essentially explored mobile gaming platforms such as in location-based games Coulton (2015). Moreover, several of these pervasive systems make use of electronical components, such as accelerometer, magnetometer, and embedded digital cameras. Besides, many systems explore environment interaction through Quick Response (QR) Codes, fiducial markers, and AR. Interconnected technologies, or the Internet of Things (IoT), incorporated mobile gaming with playful TUIs such as smart toys. Wearable technology enabled to explore physiological interactions, such as games that measure breath, brain waves, and heart rate.

Hybrid play products available on the market come from traditional toy and games industries, including robotics companies, and independent teams. Hasbro, a toy company, has several products as *Furby* Hasbro (2012), a stuffed toy robot able to connect to mobile devices. Other, are the *Playmation* Hasbro (2015) connected toys, inspired by *Avengers* franchise. Nintendo produces *Amiibo* toys Nintendo (2014); these are character figurines from popular brands, including a set of cards, and plush toys. Amiibo toys use Near-Field Communication (NFC) to transfer data to connected game consoles. In 2016, the robot company Sphero, released the wearable *Force Band* Sphero (2016) along with droid *BB8* Sphero (2015), both inspired by *Star Wars* series. Wearing the smart wristband user can control, through gestures, BB8 movements.

Following advances of digital prototyping, small independent teams are releasing new products. These advances include low-cost 3D printing and electronic components as *Arduino* and *Raspberry* platforms. Small teams are opting for crowdfunding campaigns to raise resources. For example, *DiDi* Warren (2014), a teddy bear, and *ROXs* A-Champs

(2016), a pervasive game console, have used funding platforms such as *Kickstarter* and *Indiegogo*.

1.1 RESEARCH PROBLEM & MOTIVATION

Despite novelty and potential of hybrid play interactions, many products have failed on the market. Tyni & Kultima (2016), in their research, interviewed professionals of hybrid play products field that worked within 2012-2014, and as a result, the hybrid products market experienced an experimental phase. Companies discontinued several products, while still looking for *best design practices*.

Professionals and corporations adopt different trends in their design process, including toys as a platform for several games and games associated with characters and narratives. Besides, interviewers claimed that companies make use of disconnect design practices from both toy and game design. We supposed toys & games industries could benefit with hybrid design approaches from product concepts.

Developing engagement strategies is a problem that affects both narrative and platform cases. Regarding narrative products, the content design must associate a significant semantic value. Such content refers to the game or playful activity aspects, including physical features of products. Larger companies embrace modern franchises such as *Batman* and *Star Wars* to meet it. Although, companies discontinued cases such as *Mattel Apptivity* Mattel (2013) and *Disney Infinity* Disney (2013), despite their products incorporated successful brands.

On the other hand, platform cases consist of generic products allowing several play modalities. Such products demand regular content updates to achieve long-term engagement. Two engagement strategies are allowing custom game modes and developing independent games to a single product. Moreover, many products use artificial intelligence resources to promote spontaneous play interactions and unexpected events.

Aside from efforts, many products still failing in promoting both *short* and *long-term* engagement to users. We mean as short-term engagement the inherent potential of a product to invite users for a first play experience, and as long-term, the capability to extend interaction in subsequent engagement cycles. A hybrid gameplay approach may conquer significant values to playful interface elements by embracing both semantic and interactive aspects of game objects.

The hybrid play and games field promote playful experiences connecting physical and digital worlds. While, several playful interfaces can explore AR features such as surface projection, toy's appearance is an excellent opportunity to engage users in a broader range of play interactions. Toys and smart toys present playful aesthetics inherent to their physical appearance. We believe that hybrid gaming can benefit from toy computing since these products are appealing to play even when disconnected to an external application. However, analysing market cases, toy design practices initially disregard game design concepts; so, many hybrid products that explore toy interaction have failed in promoting meaningful experiences to users.

Hybrid playful systems are complex artefacts since they use real and virtual information, and they present new challenges to both designers and developers. These challenges include defining what type of data to extract from the environment, how to present this information in the toy's interface, and selecting appropriate technologies to collect such data. A design strategy to address these issues is developing toys as meaningful interface elements. This master thesis method opted to consider 'toys' as 'physical game objects', then, these may interact with other game objects, either physical or virtual, including the environment, and people.

Hence, a 'physical game object' is a playful artefact, such as a toy, that acts as both game user interface and a game object. Therefore, when a playful interface works as a game object, it takes an active part of the gameplay or game dynamics. Understanding gameplay as the formalised interaction that occurs when players follow the rules of a game and experience its system through play Salen & Zimmerman (2004). We refer to 'hybrid-gameplay interaction' as the aspects in which a player interacts with a physical game object of any hybrid playful system.

Hybrid-gameplay aspects, however, do not comprise the full extent of a system's gameplay, such as the interaction with other virtual game objects, in-game rules or mechanics. Nonetheless, it has focused on the part of play interaction involving the physical interface elements. In that sense, when a designer determines the hybrid-gameplay aspects of a system, it consists of determining how a physical game object will act as both interface and as part of game rules, mechanics and dynamics.

Our research emphasises that when employing a hybrid gameplay approach from products concepts, might intervene in short-term engagement issues by adding to toy interface the interactive and semantic values of a game object. Moreover, we suppose that such approach might also bring benefits to long-term engagement matters.

For example, *Amiibo* toys Nintendo (2014) enable transferring character's data from real toy to connected game consoles. Even though toy interfaces aggregate playful aesthetics that matches with virtual character's appearance, such system lacks in incorporating several interactive and semantic aspects. First, toy interaction consists of a parallel action ignoring actual gameplay experience, since a player may use toys before and after engaged in interaction. Meantime, a user would perform game actions through a traditional joystick input and on-screen output.

Furthermore, toy allows recording level design information such as game stats, equipped items, bonus, and achievements. Such progress is available to players when augmenting related information on-screen. In this sense, toy interface works similar to a playful memory card, which is useful, but not entirely meaningful. We suppose that incorporating game objects features in toy design and computing might result in playful interfaces that are significant to interaction.

1.2 RESEARCH GOALS

Our research aims to assist the community with enhanced design practices for hybrid gaming and toy computing. Therefore, our primary research goal is to aid designers in creating meaningful hybrid gameplay interactions, so, our specific research goals are:

- Categorizing available HCI knowledge of hybrid games and toy computing field;
- Propose a conceptual tool that comprises different scenarios of smart and gameful play;
- Evaluate our theoretical contribution as a practical tool, using a qualitative approach, and intervening in initial design stages of new hybrid play systems.

Coming next, in Section 2 we will report both procedure and quantitative results of a systematic literature review of hybrid playful systems. Following, we will present related work to our master thesis proposal, also, detailing how we included data from a market report. In qualitative analysis, we organised mapped playful systems and products into four categories with genres. Afterwards, in Section 3 we will introduce βversion of the *IoT4Fun* relational model, presenting a qualitative user evaluation with undergraduate and graduate students. Besides, we will show procedure and results of seven semi-structured interviews that we conducted with students after classes.

In Section 4, we will start presenting how student's feedback aided us in improving model's nomenclature and its overall structure. Hence, we will compare changings and detail the final version of *IoT4Fun*, a relational model for hybrid gameplay interaction. Continuing with a qualitative approach, we will show data on a second user assessment through results from a series of creative workshops. Finally, in Section 5 we will summarise our considerations and contributions, presenting further topics for a methodological approach.

Additionally, in Appendix A, we will present two tables summarising references from both academy and market reviews. Following in Appendix B, we will detail four remaining student's prototypes and its relational models. Then, in Appendix C, we will introduce 16 selected existing playful systems, presenting its details and particular relational models. Finally, in Appendix D, we will present four of modelled concepts from the workshop series.

2 PLAYFUL SYSTEM REVIEW

Aiming a contribution relevant to academy and growing hybrid games & smart toys market, we included review methods to both scenarios. Hence, for the academy, we conducted a Systematic Literature Review (SLR) following Kitchenham & Charters (2007) guidelines, covering publications from 2008 to 2016. For market review, we selected entertainment hybrid products launched from 2012 to 2016.

Coming next in Section 2.1**,** we will present SLR procedure, its stages, and quantitative results. Then in Section 2.2, we will introduce related work to our proposal. We selected related titles using data on both included and excluded theoretical studies of the SLR. Following in Section 2.3, we will report how we included market cases to our scenario review. Afterward, using data on selected articles and commercial products, we will define a classification of hybrid game scenarios. In Section 2.4, to illustrate each of categories and genres we picked 5-10 representative prototypes and products since review results presented similar cases. A full list of selected articles along with details of product's copyright is available in Appendix A.

2.1 SYSTEMATIC LITERATURE REVIEW

According to Kitchenham & Charters (2007), an SLR aims to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology. Their guidelines covered three phases of an SLR, namely (1) planning, (2) conducting, and (3) reporting the review. Starting with *planning*, we defined our research questions and selection criteria, then, we set a string for automatic search procedure. Besides, we selected related conferences and performed snowball of references during manual search stage.

Two researchers *conducted* the method, one primary researcher for selecting papers, and other for validating findings. After three selective phases, we evaluated the remaining articles using several quality criteria. Altogether, the procedure took place between August 2015 and January 2016, where we selected studies published in 2008-2015. Later, we replicated the method to adding 2016 results, then, we performed an SLR update in January-March 2017. For this section, we *reported* both procedures and its results together.

SLR is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. Therefore, our primary research question was:

- How different game user-interface setups integrate physical playful things?

Aiding us in answering our primary question, we defined five secondary questions targeting specific aspects of hybrid playful systems:

- What are the things and its materials?
- What technologies integrate things and the system?
- What are the integrated game platforms or devices?
- What are the game dynamics and play modes?
- What are the game genres and associated thematic?

Study selection criteria intend to identify studies that provide direct evidence about research questions. We defined two main inclusion criteria as (1) *'studies in that a system with a tangible user interface has playful aspects'* and (2) *'studies in that a hybrid system has gameful aspects'.* Therefore, we managed to include researches in that physical things have playful features, such as toys and smart toys, including things or devices augmented by markers. In these, playful features appear through projection or an external display. Moreover, we included studies of gameful systems such as hybrid games, augmented board games, gamified multimedia applications, interactive storytelling, and open-ended play scenarios.

To guarantee playful aesthetics in selected studies, we defined the third criterion for exclusion: (3) *'studies that present a system with a tangible interface without playful intervention'*. Hence, we excluded studies where the game interface was: a traditional game controller, a wand, a gesture recognition device, smartphones, and haptics devices. Also, we excluded (4) *'related studies that did not focus on working prototypes'*, such as design concepts, theoretical frameworks[1], toolkits for development, design guidelines, and workshop descriptions.

We defined a temporal criterion to exclude studies published before 2008. This decision accounted the relevance of technological aspects of early prototypes and systems, and the existence of previous literature review in the field Ekaterina Kuts (2009). Kuts, in her review, selected studies on playful systems published between 1997 and 2008. The remaining exclusion or inclusion criteria were:

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[1] *We found some articles for our related work searching into excluded theoretical studies (i.e., relevant studies without presenting working prototypes).*

- Duplicated studies, (we kept one copy);
- Studies in a foreign language, (we adopt the English language);
- Grey literature (i.e., technical reports, work in progress);
- Redundant articles of the same authoring, (we kept the best rated);
- Studies that were restricted to download in our institution (without copyright subscription).

We started our SLR with the automatic search defining a string to collected data in five selected search engines; these were ACM Library, Springer Link, IEEE Xplore, Science Direct, and Scopus. The search string included terms related to user interface aspects such as *'tangible interfaces'*, *'playful interfaces'*, and *'smart toys'*. Since the scenario of interaction targeted gameful systems, we added terms related to '*game user interfaces'* and '*game controllers'*. Therefore, we set a search string as:

> *("physical artefact", or "physical object", or "smart toys", or "smart objects", or "smart artefacts", or "interactive objects") and ("tangible interfaces", or "playful interfaces", or "physical interfaces", or "game controllers", or "interactive controllers", or "game user interface") and (game, or "digital games", or "interactive environments", or "playful experiences")*

We formatted the string according to parameters of each search engine. For example, in IEEE Xplore, we had to split the string by having more than 15 search terms. For analysis, we summed results from both searches and subtracted redundant ones. In Table 1, we presented a summary of the automatic search results considering search sources and selection phases.

The five search engines returned 699 studies, after excluding 16 replicas. During the first step, we applied inclusion and exclusion criteria on title and abstract, classifying 143 articles as *'potentially accepted'* and we set 123 papers *'in doubt'*. We excluded 433 studies during the first stage, including 73 titles classified as *'grey literature'*, and three *'published in a foreign language'*.

From these, we rejected 360 articles considering its research scope, i.e. studies without working prototypes, game interfaces without playful aspects, and non-gameful systems. In the second phase, we remained with 262 studies, so, after reading both the introduction section and conclusion of papers, 119 articles met inclusion and exclusion criteria. Finally, during the quality assessment, we selected **32 studies** from the automatic search results.

Table 1 – Automatic search phases for each search engine source.

Automatic Search	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
Search Engines	**Returned Papers**	**Potential Papers**	**Evaluated Papers**	**Selected Papers**
ACM Library	191	98	51	14
IEEE Xplore	175	48	19	3
Science Direct	78	19	8	4
Springer Link	184	48	21	10
Scopus	87	61	26	4
Search Results	699	262	119	32

Kitchenham & Charters claimed that electronic search procedures are not usually sufficient by themselves and that some researchers strongly advocate using manual searches. Due to our losses in findings during automatic search phases, we decided to complement data using manual search techniques.

First, we performed (1) snowball of references on 119 selected papers from the third automatic phase. Such practice consisted of manually searching the list of references in each study. Then, we considered inclusion and exclusion criteria in both introduction and conclusion sections of papers, enabling us to add 90 related studies for quality evaluation. In a similar procedure, we added another 86 studies after (2) manually searching proceedings of six related conferences:

- International Conference on Human Factors in Computing Systems (CHI);
- Tangible, Embedded, and Embodied Interactions (TEI);
- Annual Symposium on Computer-Human Interaction in Play (CHIPlay);
- International Conference on Advances in Computer Entertainment Technology (ACE);
- Digital Games Research Association Conference (DiGRA);
- IFIP International Conference on Entertainment Computing (ICEC)

Following the quality assessment guidelines, we divided quality criteria in both generic and specific items. Accordingly, generic items relate to features of particular study designs, such as survey designs, experimental designs, and qualitative study designs. Therefore, we selected ten items relating general aspects of a study, then, we assigned them a weight (N=1).

From these, seven criteria covered aspects such: compelling justification, theoretical background, research procedure, clear goals, results discussion, study limitations, and scientific value for the field. Three criteria relate to study agreement to our research scope; so, we accounted the number of search string terms present in title, abstract, and keywords.

Kitchenham & Charters considered that specific items must relate to review subject area. Hence, we defined four specific criteria aiming to access studies with enough information to answer our research questions, and for these, we designated double weight (N=2).

First, we included an item to assure (1) user evaluation, since we aim to extract data from working prototypes. We supposed that evaluated prototypes had a higher 'quality' than on-going projects or proof-concepts. The first item was (1) *'did users evaluated the system?'* Moreover, we considered both play testing and user-centred design sessions in addition to qualitative evaluations, comparative studies, and experimental designs.

Other three items related to 'quality' in descriptions of working prototypes. We intended to access data from (2) system's setup, including (3) accurate information on playful things, and (4) how system integrated these with technologies and user interactions. Thus, remaining items were:

- (2) 'did the study well described the overall system setup?';
- (3) 'did the study fully explained the playful things present in the system?';
- (4) 'did the study presented how the things integrate within the system?'.

During the quality assessment, we scored all items either with '0' to *'No'*, '0.5' to *'Partially'*, or '1' to *'Yes'*. Based on evaluating a study with '1' to all general items and a partial score (0.5) to all specific criteria, we defined a 70% cut-off point. Along with criteria evaluation, we recorded summaries of studies naming their things and general system aspects, including a short description of the interactive scenario.

In summary, we read all sections of 295 articles and evaluated them using the 14 quality criteria. After excluding 185 studies scored under 70% in quality, we selected 110 articles above average. However, we identified that eight selected papers were redundant (e.g., studies of the same research subject and authoring), so, our final selection resulted in **102 articles.** A full list of selected papers and its references is available in Appendix A.

2.2 RELATED WORK

IoT4Fun aims to embrace different scenarios of hybrid gaming and smart play. Although several authors have addressed efforts on organising such knowledge, current state-of-the-art still missing practical tools able to comprise a larger number of interface setups. For this section, we organised related work in chronological order, also highlighting differences and similarities to our proposed model. We selected titles of this section consulting theoretical studies found during the SLR, including some of the rejected articles (i.e. relevant framework papers that did not present working prototypes).

Ulmer et al. (2005) presented a framework to tangible interaction named *Token+Constraint*. Tokens are spatially reconfigurable physical things representing digital information. Constraints are restricting regions within a user can place a token. Such interaction model presented two phases: *associate* and *manipulate*. The associate refers to placing a token within the physical restrictions of a constraint, including removing the token. The second phase comprises systems where users may manipulate tokens within the limits of this constraint, i.e., sliding a token on a tablet screen.

Token+Constraint framework applies to several smart play scenarios, such as in tabletop interaction and augmented board games. Advances in technology, such as active tokens, allowed this framework to evolve to an additional *Token+Token* interaction Mora et al. (2016). However, still many other play scenarios that do not fit in this interactive paradigm, such as embodied and embedded interactions. *IoT4Fun* relational model differentiates by aggregating both indoor and outdoor scenario, comprising interaction modalities from visual and manipulation tasks to embodiment and pervasive experiences.

Eva Hornecker (2010) presented a tangible interaction framework comprising four aspects: *Tangible Manipulation, Spatial Interaction, Embodied Facilitation*, and *Expressive Representation*. Then, she applied theoretical framework as a creative method to designing hybrid systems. The proposed method used a card game set during brainstorming sessions, representing four framework aspects. Each group of cards had a colour, and each card had a related question, along with representative images and subtitles.

The research goal was to use cards to promote discussion among participants in brainstorming sessions. Hornecker applied the method in 10 sessions with professionals and students. As a result, subjects produced games and interactive installations, for both indoor and outdoor environments. Accordingly, the cards enabled groups to discuss the relevance of each framework aspect, facilitating ideas formulation.

Similarly, our research adopted a theoretical model as a practical tool for the creative process. We choose such approach since its detailed structure enabled to name several aspects of playful systems. These, include physical and social interaction, types of I/O technology, and the relationship among interface elements. In addition to employing the model as an ideation tool, IoT4Fun enabled creators to refine their game concepts using model structure.

Guo et al. (2010) introduced a framework on aspects that make a pervasive game based on literature review. Analogous to our work, the framework comprises systems such as smart-toys, augmented tabletop games, location-based games, and AR games. Their model presented four perspectives; first, the *temporality* classifying how players can join gaming turns, and these are closed or open-ended. Second, the *mobility* perspective dividing games with a fixed location to large interactive environments, where players have enough space to move their bodies. Third, the *perception* perspective distinguishes how system extracts real-world information, and in how both users and the system translate such information, including an overview of technologies to collect such data. Finally, the *social* perspective reflects relationships among players and social influence of game purpose and thematic.

The authors turned perspectives into parameters, aiming to measure the pervasiveness level of each system. Likewise, we used our model to describe aspects of existing playful systems. However, rather than set a comparative score, we aimed to organise data, presenting to designers what are possible design aspects of such systems.

Magerkurth (2012) presented a theoretical framework to describe interaction domains for hybrid gaming systems. Similar to our proposal, he built a framework on literature review and observing aspects of board games and digital games. The research focused on multiplayer gaming scenarios involving the input of real-world information through smart things, and GUI output presented on a screen.

The framework comprised three domains: first, a *social domain* varying as public, private or shared. Second, a *virtual domain* that associates with the social domain by the exchange of information and game states. Finally, there is a *physical domain*, where users can have access to real world properties and tangibility.

The author believed that a goal of such games is to capture a traditional and co-located experience of physical spaces. Therefore, he defended using non-intrusive pervasive technology to enhance such experiences. Despite this, we encourage designers to employ digital resources in a meaningful way. Mixing digital and real information may create new formats of gaming experience, instead of simply enhancing them. Moreover, we find topics on information sharing a relevant subject to designing such experiences, and we included similar aspects in our model.

Garde-Perik et al. (2013) analysed I/O relationships of active tangibles. Authors aimed to understand user's perception of information to creating meaningful I/O experiences. The model combines two parts: the *state change* and *information access*. The first refers to I/O aspects of user perception of the physical world, and the second relates how smart devices collect information (input), including how the system translates such data (output). Then, connecting two I/O models appeared a cognitive domain regarding internal user's perspective, followed by two shared physical and digital spaces.

The authors' framework presented an educational game as a case study. However, it does not focus on gaming scenarios. We find that designers must account relationships among people and I/O technologies to create meaningful toy interaction. Thereby, our proposal included I/O aspects of the relationship between individuals and things.

Seeking to describe a broader range of play scenarios, Paul Coulton (2015) defined four interaction spaces for IoT game object interaction. The author used Jesper Juul's (2010) definition of game spaces to present a scenario classification for IoT gaming systems. The research categorised four playful scenarios: IoT object, IoT object in the player space, IoT object with a tablet, and IoT object with the screen. The goal was to present available design spaces for interaction, these are the screen space, player's space, and 3D space combining both virtual and physical spaces.

Coulton recognised a few topics, such as how a system could present feedback on game spaces. Moreover, he presented data on types of technology promoting such interactions. Similar to our work, the author considered physical things as game objects, and his model covered different scenarios of smart play. However, Coulton presented an overall view of such situations, so slight contributing to how such game spaces would affect specific game design decisions. In our model, in addition to defining design areas, we identified interactive aspects for hybrid-gameplay interaction, aiding creators in determining response formats for game actions.

2.3 MARKET REVIEW

Another research goal is to extend contribution to the playful systems field including data from market cases. Our interest in embracing industry products underlies in a fact that a significant number of end-users have experienced such products. Besides, those are a result of a long design process, including several prototyping stages such as co-design practices and user testing. In the review, we selected **120 cases** among smart toys, toy robots, playful gadgets, and hybrid games & applications. A full list of the mapped products is available in Appendix A.

First, we found cases consulting (1) the catalogue of several brand websites and toy stores i.e. *Japan Trend Shop*, *Hasbro, Fisher and Price, Disney,* and *Mattel*. Then, we searched on (2) lists of projects in two crowdfunding websites named *Kickstarter* and *Indiegogo*, and (3) followed results of related search terms on *Google*.

Despite academic review temporal-cut (2008-2016), we selected products launched from 2012-2016, including first trimester of 2017. In Figure 2, we presented an exported data from *Google Trends* comparing the relevance, in number of searches, between three terms or key words that we used on market review. Such data ranges from 0 to 100, where 0 represented popularity of searches lower than 1%, while 100 was the popularity peak of each search term.

The term ‘smart toys’ presented a solid behaviour in 2008-2016, indicating a regular search peak between November and December during all years. We attributed such phenomenon to (1) end-year holiday’s season, a normal high of both selling and buying products motivated by festivities such as Christmas. Moreover, this period is (2) timing of several new products launches of related sectors such as toys, games, and electronics.

Analysing data on terms ‘toy app’ and ‘toys app’ we found a similar search peak behaviour. However, the comparative relevance of both terms first presented values above 50 at mid-2012, which represented a half-popularity. Such data suggested the launches of connected toys lines and the urge of correspondent applications on app stores in this period. For example, 2012 was the year launch of a popular connected product, the robotic plush-toy *Furby Boom* from toy company Hasbro (2012).

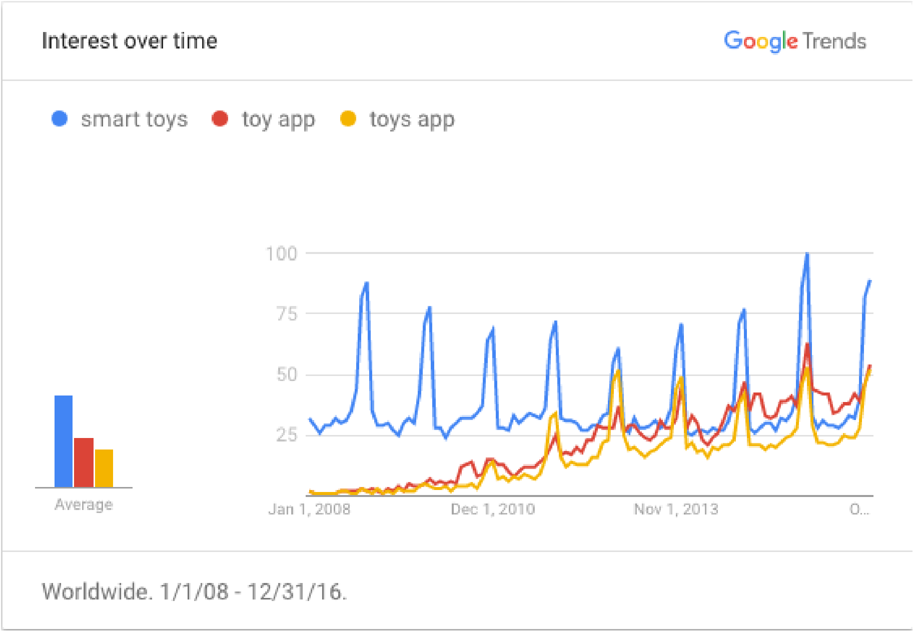

Figure 2 – A chart is comparing the relevance of three specific toy-market search terms between 2008 and 2016. Adapted from: www.trends.google.com

2.4 PLAYFUL SYSTEM CLASSIFICATION

After selecting results from both reviews, we proceeded with the data extraction phase. We will detail how we extracted and managed data for the research proposal in Section 3. In the present section, we focused on showing data usage as means to defining a playful system classification.

In qualitative analysis, we used summaries taken during the quality assessment stage from the SLR, and when necessary, we consulted selected articles to find unmapped information. Also, to extract data from market results, we used text, pictures, and audio-visual materials available online. Thus, our principal sources were product's websites, blogs & newspapers, commercial videos, and user's reviews on *YouTube*.

First, we started classifying systems by defining their general features, and then we identified game genres and types of promoted play. Following, we proceeded to detail things present in the systems (i.e. toys, smart toys, tablets, computers, and digital cameras). Afterwards, we extracted data on how these things integrate with the system and its technologies. We mapped interaction modalities involving people and things, such as the use of their body parts (i.e. head, upper limb, or hands).

By observing people on systems, we could recognise social relationships among them, including play modes (i.e. in pairs, team, and single player). Besides, we collected data on how people had access to things, and to system information. Furthermore, we identified target audiences for each system, and how and where people locate in the interactive environment.

Based on data summary, we distributed the selected systems into four categories including genres; these are *Children's Play*, *Games & Applications for Fun*, *Serious Games & Applications*, and *Interactive Storytelling* (see Figure 3). In the next subsections, we detailed each category, presenting its related genres and giving 5-10 system examples.

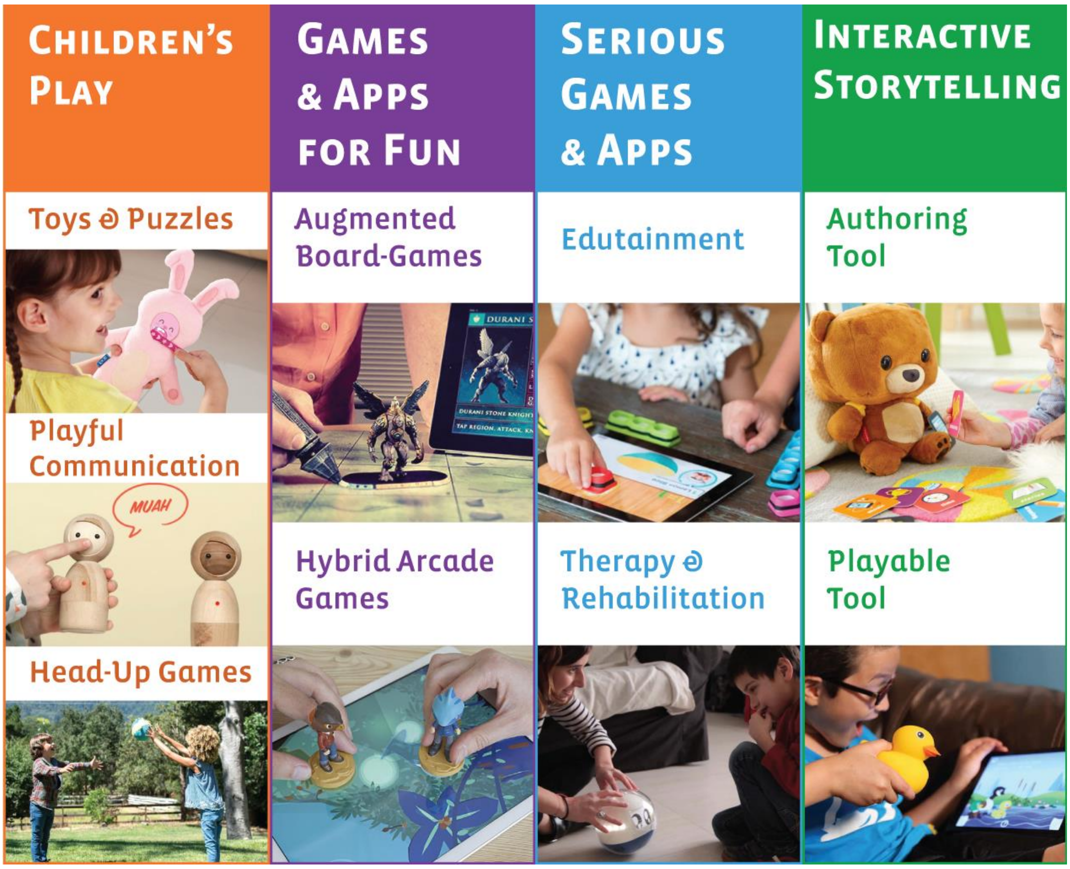

Figure 3 – The hybrid playful system's categories and genres with representative images.

2.4.1 Children's Play

Several authors claimed that playful systems with a tangible interface are attractive for children Zaman et al. (2012). According to our data, over 100 systems promote play activities for toddlers of different ages. Therefore, the Children's Play category refers to a set of hybrid systems that has characteristics related to children's traditional play and games.

2.4.1.1 Toys & Puzzles

Toys & Puzzles genre includes playful interactions focused on enhanced toys or puzzles that make use of computational resources. Usually, such interactions present a minimal interference on original play purpose.

Antle et al. (2013) presented a tangible interface to assist players in building a jigsaw puzzle. The system embedded fiducial markers on the bottom of each puzzle piece, enabling an infrared tabletop to identify the pieces. When a child places a right or wrongful puzzle piece on the table, the system provides correspondent visual and audio feedback.

Similarly, happens in the *Osmo* Tangible Play (2014) platform where a tangram puzzle application presents to players the correct position of pieces for each level. Then, the player builds a puzzle following practical instructions on a tablet screen. The system can recognise real pieces' position through a mirrored device placed on the tablet's webcam. Hence, both systems make use of technologies to enhance play experience by augmenting and checking puzzle rules in real-time.

Moreover, several selected studies presented interactive plush toys Abeele et al. (2008), Avrahami et al. (2011), and robotic toys Cooney et al. (2011), Gomes et al. (2011). This sub-genre is popular on market scenarios, as Furby Boom Hasbro (2012) presented in Figure 4. Children can play with *Furby* as a traditional plush toy like in pretend-play (i.e. feeding it, cleaning it, or putting it to sleep). Using a connected application, a child can perform those play actions experiencing multimedia feedback from virtual resources.

Figure 4 – Furby Boom: a) a user playing a connected game, b) children playing shower application, c) a user checking Furby game stats, and d) Furby using a connected sleeping mask toy. Adapted from: www.hasbro.com

A related case is *DiDi* Warren (2014) a plush toy case shaped like a teddy bear that split an IPad screen in two. Application ‘brings the toy to life’, so, children can feed DiDi with several food toys with touchpoints, and brush its teeth. Another interesting aspect of such toys is that they are still playable while disconnected since their playful aesthetics are appealing to play.

Other recurrent cases are smart building blocks as PlayCubes in Jacoby et al. (2009). PlayCubes is a tangible system of several magnetic blocks that can attach and sense each other through embedded electronic components. A player can either build any set of blocks, as a free-play interaction or follow practical instructions on a screen.

A mix of building blocks with robotic toys is the kinematic toolkits Topobo Parkes et al. (2008) and Posey Weller et al. (2008). Such smart toys consist of active and passive blocks able to record and reproduce physical movements. A user can join blocks to build a robotic dog, and then, record movements such as walking or wagging its tail and so replay it several times.

In summary, besides such toys integrate digital contents these still assume their traditional purpose of engaging children in free-play activities. Virtuality provides either feedback to intangible play experiences such as pretend to play situations or augments interaction rules, facilitating or increasing challenges.

2.4.1.2 Playful Communication

Playful Communication genre covers systems that enable free-play activities to promote real-time communication and social interaction among participants. Several systems focused on familiar contexts, such as parents and children, or among siblings.

Freed et al. (2010) presented three designs of augmented dollhouses to assist playful communication of family members who live in separate houses. Then, children would enjoy a collaborative free-play experience while remote located. Similar systems appeared in two studies, first, video playdate, where siblings can visualise two overlapped physical play spaces through projection Yarosh et al., (2010). Second, the Sharetable Yarosh et al. (2009) that aids parents and children to work and play together in a table combining a videoconference and projection.

Those systems had to set up a communication channel among remote participants, by either video or audio. Playful sounds and voice messengers are recurrent products on the market, such as *Talkie* from Toymail (2016). In Figure 5, we presented *Avakai* Vakai (2016), two Bluetooth connected wooden toys that can both send sound messages to each other, and interact with children stimulating their imaginative play experiences.

Participants using such product can experience both remote and collocated play. Other collocated systems are *Ubooly* Smart Toy (2016), *Hello Barbie* Mattel (2016), and *Cognitoys* Cognitoys (2015), so those promote either playful communication, imaginative free-play, including interactive storytelling.

Figure 5 – Avakai toys: a) a figure representing BLE toy connection, b) a user sending sound messages, c) a user receiving a sound message, and d) children using toys outdoors. Adapted from: www.vakai.com

Playful communication suits among people with previous knowledge of each other, such as friends, colleagues, and co-workers. Melonio et al. (2016) presented Turn Talk, a smart toy to mediate playful communication among children in a school environment. Such toy has a pentagonal shape, corresponding position of each player. The toy can account how many times a child took a turn during a chat providing Light Emitting Diode (LED) feedback. Therefore, the entire group can visually access how participants shared dialogue. The toy can also read cards to define conversation topics, then, children receive coins as a reward to achieve a balanced chat.

However, studies presented evidence that playful communication still a challenging interaction among strangers. Sakamoto et al. (2015) compared different remote play experiences of *Yugi-Oh Trade Card Game* inspired by Japanese television series. System setup enables players visually access opponent's deck through projection in a table, also establishing a videoconference among participants. Research results showed player's preference to use the system with friends, instead of engaging in playful communication with strangers, especially on face-to-face video mode.

2.4.1.3 Head Up Games

Head up Games genre refers to a set of playful activities inspired by traditional children's games such as *'tag'* and *'hide-and-seek'*. These games present open or negotiable rules and happen at outdoor or large environments. Several of these games explored embodiment interaction and physical exertion Hendrix et al. (2008), Soute et al.

(2010).

In Figure 6, when choosing the toy named *Chirpie* Fuzzy Flyers (2016) children can enjoy an augmented version of *'egg toss'* game. Chirpie is a plush bird toy shaped like a ball allowing detecting relative position, speed, and collision. The toy can determine either a successful movement or if 'egg' broke during play.

Figure 6 – Fuzzy Flyers, a) children playing Egg Toss game, b) a girl playing Dancy Party game, and c) available toys Chirpie and Coco. Adapted from: www.fuzzyflyers.com

Shen et al. (2013) introduced Beelight, a smart bee that collects colours from objects and environment. Each child can pursue a Beelight and enjoy competitive colour-catch games using a shared honeycomb. Wearable technology for children is a recent opportunity case for the head up genre.

A popular commercial line of connected toys is *Avengers Playmation* from_Hasbro (2015). This line presented wearables such as *Ironman* hand gear and *Hulk* fists. Players can interact either with each other using gears or with smart figurines of heroes and villains.

Many connected devices allow customising or creating new games, such as RaPIDO from Soute et al. (2013) and commercial platform *ROXs* A-Champs (2016). In both examples, users can either programming new interactions or editing available games.

Bekker (2010) presented in a research five smart toys and devices destined to open-ended play activities. ColorFlare enables users transferring corresponding LED colour from one toy to another through proximity. Each toy has predefined LED feedbacks for shaking and rolling interactions. Authors claimed that providing feedback of physical interaction to players, allows them to create their social play experiences.

2.4.2 Games & Applications for Fun

Games & Applications for Fun category referred to systems close to digital games but integrated with tangible interfaces. Hybrid games present fixed rules with a clear distinction between physical and digital information.

2.4.2.1 Augmented Board Games

Augmented Board Games genre comprises systems similar to traditional board games that make use of digital resources. Virtuality can both augment game rules and integrate dynamic game content. Moreover, such games require turn-based mechanics, and their setup must allow developing strategies through manipulation of game pieces or characters.

In Figure 7, Golem Arcana Harebrained Holdings (2014) is a hybrid board game connected to a management application. This product explores both types of features, first, augmenting character's information through RFID figurines, and second, triggering dynamic game events during gameplay.

Figure 7 – Golem Arcana: a) the general game structure, a smart pen, several active figurines, a game board and a connected application, b) a player augmenting character's information on the tablet, and c) a screenshot presenting real pieces positioning for the game round. Adapted from: www.golemarcana.com

Hinske & Langheinrich (2009) presented an augmented version of the W41K role-playing game (RPG). Authors used RFID antennas and readers to detect the relative position of all physical game elements, therefore, assisting players on gameplay rules. Despite, in Marco et al. (2012) two virtual displays represented different views of an interactive board in a farming game. Their game setup used an NKVision infrared tabletop, and physical animal figurines had fiducial markers to allow identification. In this sense, a general hybrid board game setup includes an interactive board and interaction with multiple tokens and any game element is either physical or virtual.

In literature, several systems make use of AR and computer vision resources to detect both board and pieces Xu et al. (2008), Huynh et al. (2009). Meanwhile, in the market, we find cases exploring sensitive touchpoint toys for commercial tablets and active technologies such as NFC. For example, PlayTable PlayTable (2016) is as Wi-Fi tabletop platform for augmented board games that detect attached NFC tags on physical things. Custom tabletop uses Android Operational System, enabling to connect with smartphones and other compatible devices.

A commercial game that combines physical and virtual pieces, including passive and active tokens is World of Yo-ho from French company Volumique (2014). The main setup consists of a physical game map representing the game world, along with smartphones representing player's boat. Through phone display, the player can visual access the virtual boat located at a corresponding map area. First, a player must place a smartphone on a required map constraint. During gameplay, the system uses accelerometer data to predict its relative position on the game board. Players interact with real game characters and a card deck.

Mora et al. (2016) presented a hybrid version of collaborative board game 'Don't Panic!'. Their research goal was to explore game design aspects using active and passive tokens, and token+token interaction. The authors replaced token pieces with Sifteo Cubes Sifteo (2012), enabling interaction among pieces using NFC technology. Also, they replaced a fixed card deck with a card printer to increase random game events.

2.4.2.2 Hybrid Arcade Games

Hybrid Arcade Games genre comprises agile or action games combining a virtual world displayed on either a screen or projector connected to a playful tangible interface. Classic arcade games presented many musical games, first-person shooters (FPS), and driving games. New hybrid arcades increased tangible interaction to multiple game genres, including RPG and narrative centred designs.

Skylanders Activision (2013) introduced NFC collectable figurines connected to various game consoles. Then, in following years, the industry launched similar cases such as *Amiibo* Nintendo (2014), *Disney Infinity* Disney (2013), and *LEGO Dimensions* LEGO (2015). However, several products kept exploring classic genres, such as driving games, since these could benefit from toy interaction.

Dang & André (2013) presented TabletopCars in Figure 8, a collection of four games using radio controlled toy cars on a large *Microsoft Surface* tabletop. In Parcours game, a player must drive a car through a defined path, while avoiding both virtual and physical obstacles. Similar commercial products are *Cannybots* Cannybots (*2015*), *Anki Overdrive* Anki (2015), *Disney AppMates* Disney (2012), and *Apptivity Hot Wheels* from Mattel (2013).

Figure 8 – Tabletop Cars: a) a user creating a path in Parcours Game, b) a collection of physical obstacles, c) two players competing in Car Crashing, and d) players competing in Fastest Lap. Adapted from: Dang & André (2013).

Despite connected game consoles and large screens, mobile gaming market comprises most commercial products of this genre. A usual setup adopts conductive touchpoint toys for tablets. Moreover, such games make use of multiple device features, such as camera, internal electronic components, and connection modules i.e. Bluetooth, NFC, and Wi-Fi.

Oniri Islands from Tourmaline Studio (2017) is an RPG adventure where players use two character figurines with accessories. Players perform both navigation and attack actions using character toys with conductive touchpoints. When a player equips toys with different conductive masks, these conquer power-ups to characters.

The literature slightly explored touchpoint toys Bech et al. (2016), and many toy-tablet studies make use of AR and computer vision as interaction resources. Avrahami et al. (2011) presented four prototypes for Portico platform. The platform is a tablet attached to digital cameras, allowing the system to identify pieces on the screen and a limited outside area. The authors had prototyped hybrid arcade games such as a space shooter, and a soccer match game.

Other selected prototypes exploring AR technology, used mobile projectors, these are Motionbeam Willis et al. (2011), and HideOut Willis et al. (2013). Furthermore, two studies implemented new prototyping resources such as flexible materials Slyper et al. (2011) and transformable rigid structures Katsumoto et al. (2013).

The selected studies presented prototypes using tangible gaming platforms such as *Sifteo Cubes* Sifteo (2012). These are modular interactive displays enabled transferring data from each other by proximity. Games as Fat and Furious Pillias et al. (2014) and Maze Commander Sajjadi et al. (2014) differentiate by presenting both map and interactive game elements distributed into multiple physical pieces. Maze Commander combines tangible interaction with a virtual reality (VR) headset. As a collaborative experience, one player wears an *Oculus Rift* to visualise game map, so, he/she gives instructions to a second player in charge of controlling character's movements with cubes.

Additionally, this genre includes large indoor installations, such as in modern arcade stations, interactive museums, and amusement parks. Yao et al. (2011) introduced Rope Revolution system, combining four games based on interaction with a rope. Among games, authors developed a rope-jumping system with a remote game mode, so that players could enjoy a collaborative experience in different installations. Another similar arcade is Remote Impact, an exergaming experience inspired by martial arts Mueller et al. (2014).

2.4.3 Serious Games & Applications

According to Zaman et al. (2012), several authors claimed that tangible interfaces are easier to learn and to master than traditional mouse-keyboard or joystick. *Serious Games & Applications* category covers systems that promote fun while dedicated to serious purposes. Many systems target contents for children, elderly, and people with disabilities. Although systems setup and gameplay features are similar to previous categories, we classified those based on their game content.

2.4.3.1 Edutainment

Edutainment genre covers tools and serious games supporting both practical and theoretical learning. Such systems aim at either basic or specific educational topics.

Basic topics comprise language and math subjects such as numerals, letters, and colours, including tools for improving children's vocabulary and spelling Hafidh et al. (2014) and Zidianakis et al. (2016). Kubicki et al. (2012) presented TangiSense, a LED tabletop to aid kids to learn about colours. Children interact grouping physical objects in a respective colour area on a tabletop. Furthermore, they receive feedback from a wizard character figurine.

Tiggly Tiggly (2014) in Figure 9 is a commercial platform covering most of the basic learning topics. For example, in math applications, players manipulate squared conductive toys representing numeric units. Kids can use them in four different applications including science and cooking games. The platform also offers toys shaped like numbers, letters, or geometric forms.

Figure 9 – Tiggly: a) children playing Tiggly math application, b) a child manipulating a geometric shaped toy, c) a Tiggly word application, and d) two available toys set boxes. Adapted from: www.tiggly.com

A recurrent learning topic related to social and community aspects such as ecology and sustainable environment Speelpenning et al. (2011), Antle et al. (2011), Furió et al. (2013). Okerlund et al. (2016) presented Synflo a serious playground to teach bio-genetics concepts. The authors compared two versions of the game combining *Sifteo Cubes* with physical things. Their results suggested that combining digital and physical resources improved social interaction among adults and children.

Numerous systems introduced tangible programming tools. Scharf et al. (2008) presented Tangicons, a coding prototype based on building blocks and pictograms. These physical programming languages make use of pictograms to represent available ‘actions’ and its ‘conditioners’, i.e., choosing ‘move’ either to ‘left’ or ‘right’ Furthermore, the market is investing in programmable wearable for young girls such as JewelBots Jewelbots (2015) and Linkitz Linkitz (2015).

Another usual setup consists of using tangibles to programming both navigation and robot’s behaviour Horn et al. (2009), Wang et al. (2016). Commercial coding robots are *Cubetto* Primo Toys (2013), *Code-a-pillar* Hasbro (2016), *Ozobot* Ozobot & Evollve (2015), *Dash & Dot* Wonder Workshop (2015), and Mindstorm lines NXT LEGO (2012) and EV3 LEGO (2017).

Playful training is a sub-genre comprising practical learning systems that combine game design aspects with playful interfaces. Fogtmann (2011) presented TacTower, a setup of four connected tower LEDs for physical exertion. The authors introduced the system as a training platform for professional handball players. In Blocker gameplay, a player must conduct a LED ball from the first tower to end tower. Then, the opponent places blockers to prevent another player from advancing, and competitive play activities increase both exertion and challenge while changing distance among towers.

Yamabe et al. (2013) presented four playful training systems combining projection and AR technology. EmoPoker is a training poker system allowed to collect heart rate data indicating player's emotions during play. Receiving audio and visual feedback a professional player trains his/her bluffing performance. Various industry products aim to change multiple aspects of kid's behaviour. These include toys and games connected to toothbrushes, such as *Playbrush* Playbrush (2015) and Brushies Sasa Sallamon (2017).

2.4.3.2 Therapy and Rehabilitation

Therapy & Rehabilitation genre comprises systems destined to training either people's cognitive or motor skills. Besides, many systems allow modifying both challenge and interaction modality according to patient requirements. In this sense, such systems may include editing tools for professional therapists, teachers, or parents.

Hengeveld et al. (2009) introduced Linguabytes a tangible console for phonological therapy. The game console in Figure 10 provides three interface modes for toddlers practice speech tasks using RFID augmented puzzles, cards, or plush toys. Therapists access an interface terminal to programming game actions, and customising content using RFID tags, therefore, creating new playful interfaces for patients.

Figure 10 – Linguabytes: a) general system setup, display, a base module, an additional module, and a therapist module b) the BookBooster module, c) the Combination module, and d) several figurines, puzzles, cards and available wooden modules. Adapted from: Hengeveld et al. (2009)

Autistic children are a recurrent group of users in such systems since studies presented evidence that robot play interaction improves their social skills Spiel et al. (2016). A successful product is *Leka* Leka (2015) a robot ball founded on *Indiegogo*. Leka has connected applications and games, and offers customizable colour, sounds, and vibration feedbacks. The robot works as a custom social tool for parents and therapists.

Keepon Kozima et al. (2009), is a toy robot embedded with cameras on its eyes. Using computer vision techniques enable the toy to physical and social interact with autistic children performing movements and funny sounds. An available commercial version named *My Keepon* Wow! Stuff & Beatbots (2011) focused on imitating children body movements or reacting to music and environment sounds, such as in dance and play activities.

Li et al. (2008) presented a tabletop game to support motor rehabilitation for children with cerebral palsy. Kids interact with colour puzzle games using three playful interfaces shaped like a hammer, a static cube, and a Rubik's cube. Alternating toys, the system allowed training both fine and gross motor skills.

Vandermaesen et al. (2014) presented PhisiCube, a rehabilitation system based on *Sifteo Cubes* destined to upper-limb therapy. In LiftACube game, a patient practice gross motor skills by lifting and stabilising cubes next to other. Player trains four fine motor movements of neighbouring, pressing, shaking and flipping.

Another recurrent group of users are elderly people. Lee et al. (2009) presented four installations to training their both cognitive and motor skills. In Sensorial Bike setup, a user rides a connected bicycle in an outdoor projected environment, when competing for a race and avoiding virtual obstacles. The system enables to collect patient's physiological data to later analysis by physical therapists.

Several systems promote interaction between patients and people with no disabilities, such as with family members Gerling et al. (2015) including interaction among traditionally developed children and that of special needs Garzotto & Bordogna (2010).

Two games focusing on anxiety therapy are Tobe, a wearable system integrated with a wooden character Gervais et al., (2016), and ChillFish, a respiration game destined to people with Attention Deficit Hyperactivity Disorder (ADHD) Sonne & Jensen (2016).

2.4.4 Interactive Storytelling

Interactive Storytelling category comprises systems enabling a user to either create or take part on interactive plots. Such storytelling systems make use of individual pieces representing both characters and other environment elements.

2.4.4.1 Authoring Tool

Authoring Tool genre includes systems focused on creating narratives based on the interaction of characters and other plot elements. A player may manipulate interactive pieces, such as objects and figures, therefore, creating, editing and recording their stories.

Hunter et al. (2010) introduced TeleStory, an authoring system using *Siftables* cubes. The system presented 22 plot variations, so, children manipulating either a cat or a dog character would define character's actions, such as 'a cat' goes up to 'a three'. The system includes environmental actions, like setting the time to 'night' by adding 'a moon' cube. A large screen displays in real-time each related animation pieces. Similar interaction appeared on Zhou et al. (2008) using an AR cube with fiducial markers connected to a digital camera.

A commercial toy using computer vision technology is teddy bear *Smart Toy* (2016) from Hasbro in Figure 11. Children can either play pre-defined stories or create unexpected plot variations showing cards in front of two embedded cameras in the toy's eyes.

Figure 11 – Smart Toy: a) things available in the system, a bag, a card set, and a smart plush toy connected to an application, b) a child interacting with a card, and c) a parent helping a child with the story cards system. Adapted from: www.hasbro.com

Several systems enable to insert traditional toys as characters of interactive stories. StoryCube Wang et al. (2014) introduced a LEGO box attached to any plush toy using RFID tags. A player manipulating StoryCube can create stories about a correspondent virtual character displayed on a digital application. Similar to a joystick, the box contains buttons and levers; so, a user can select terrain and other interactive objects, and then, navigate a character through a 3D environment.

'Picture This!' system Vaucelle & Ishii (2008) presented a narrative based on pretend play using two dolls embedded with cameras and motion sensors. *Oliba* from

The French company Smarty Crew (2016) is a 'toy-telling' device enabling parents recording voice bedtime stories for their children listening attached to their favourite plush toys.

2.4.4.2 Playable Tool

Playable Tool genre covers systems with a pre-defined narrative, and users engage in experiencing a plot similar to a gaming experience. Such systems enable players making decisions for characters while exploring different plot paths.

Shen & Mazalek (2010) introduced PuzzleTale in Figure 12, an interactive storytelling system allowing players to interact using jigsaw puzzle pieces. A player places a game piece representing a dog character in different constraints on a tabletop. Placing the dog puzzle, a user makes the dog meeting a new character or experiencing a key plot point. According to selected order of events, a player may generate several endings for the dog story.

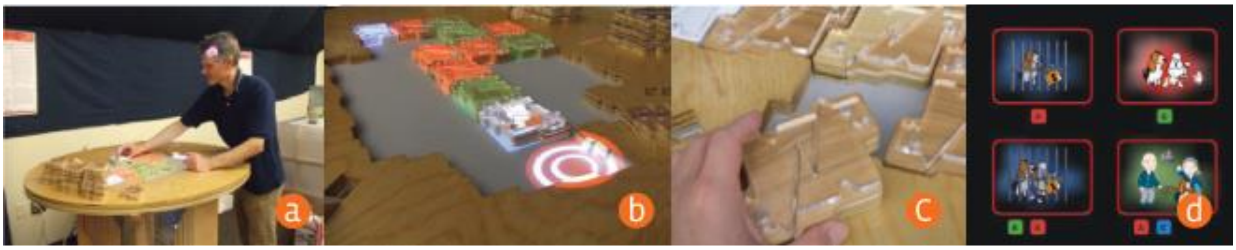

Figure 12 – PuzzleTale: a) a user playing PuzzleTale tabletop system, b) visual feedback of pieces on the tabletop, c) a user placing a puzzle piece in a constraint and d) four examples of key point plot. Adapted: Shen & Mazalek (2010).

In turn, *'Edwin: the duck'* Pi Lab (2015) is a Bluetooth rubber duck speaker promoting similar experiences when connected to a mobile application. Users can experience the daily events of Edwin, such as waking it up, brushing its teeth, popping balloons, and competing in a lake race.

A wearable named *Herokins* Coming Soon-Tech (2017), live on *Indiegogo*, works as an agenda, but integrating storytelling aspects, so, the system turns children's daily activities in story quest series. For example, a story quest may involve stimulating children in helping their parents doing groceries.

A few studies combined both authoring and playable interactions Farr et al. (2010). T-Games is an authoring tool platform using fiducial markers, to generate playable tools to children experience as games Mendes & Romão (2011). Han et al. (2015) introduced a study using tangible and robot interaction for engaging children in dramatic play. There, kids as actors reproduce a plot wearing AR headbands, following scenarios displayed in a social robot.

In this section, we presented a playful scenario review and classification. Coming next, we will show an overview of research method, presenting how we used data from scenarios to propose a relational model for hybrid gameplay interaction; also, submitting data of two user evaluations.

3 MODEL βVERSION & EVALUATION

In Figure 13, we showed a timeline overview representing our research flow. Along a two-year practice, we started performing the SLR and a market review, so we extracted data on playful systems to propose a βversion of the relational model for hybrid gameplay interaction Albuquerque et al. (2016). Towards a qualitative evaluation, we inserted the model βversion in a 16-week project-based class to design hybrid games with playful interfaces Albuquerque et al. (2017). The classes were multidisciplinary including both undergraduate and graduate students from Design, Computer Science and Engineering fields.

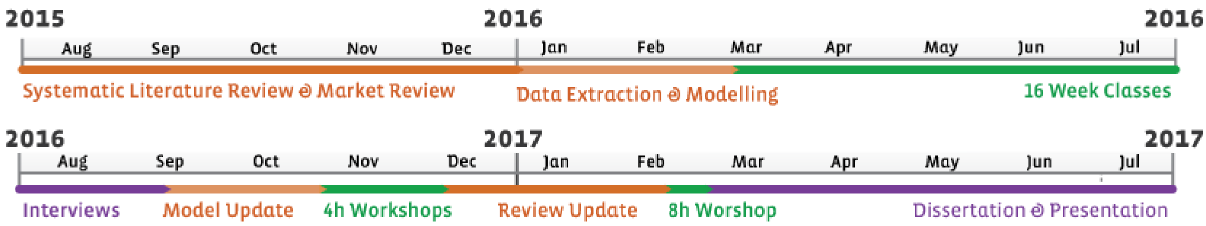

Figure 13 – A chronological timeline representing research flow and methods.

During classes, we performed observation techniques, and we accessed student's outcomes through the produced exercise sheets, presentation materials, including **user** testing reports, and documentation. After classes, we conducted semi-structured interviews with students aiming to access model usefulness in describing their systems, including overall impact of both model and complementary tools.

Subjective evaluation of student's feedback enabled us to identify points of the model that still needed adjustments, and we proposed a model update. As a goal to evaluate changings, we applied the model update in a series of three creative workshops. The workshops had 4 and 8 hours' length, focusing in first design stages of conception, ideation, and low-fidelity prototyping.

Meanwhile, we updated the SLR and market review including data from 2016 articles and commercial products. Then, we organised collaborations and produced this master thesis document. Hence, to present the modelling stages and their evaluations, we divided the study results into two sections.

In the present section**,** we introduce the *IoT4Fun βversion*. Section 3.1 gives an overview of its structure, also presenting how we used it to describe a playful system sample. Following Section 3.2, details the 16-week course schedule, introducing each stage results, and describing two of student's prototypes using model βversion. Later, in Section 3.3, we show interview's procedure and outcomes, discussing student's perception of model usage.

Next in Section 4**,** we will present how we improved βversion nomenclature using student's feedback. Then, we will detail IoT4Fun final version including how we used it to describe 20 hybrid playful systems. Furthermore, we will present data of a second user evaluation.

3.1 IOT4FUN βVERSION

A game interface is as means that a player can access to game world functions, and this comprises both inputs and outputs. Hence, those are either physical or digital. According to Schell (2008), a game interface must allow players feel in control of their experiences. Interactivity plays a major role in the overall game experience, and this takes place across all levels. Starting from a regular interaction of the game's objects and pieces, to the social interaction of players, to the cultural interaction of the game with contexts beyond its space of play Salen & Zimmerman (2004).

We modelled playful interface systems towards a gaming interaction approach. Unlike from a traditional game interface system, in addition to controlling functions, playful physical interfaces have appropriated from semantic values of the game objects. Proposed interactivity goes ahead of a general game interaction flow that presents *interface as a connecting membrane between player and game environment* Schell (2008). Playful interface design must comprehend its elements as an equivalent entity of interaction.

Based on the data summary used in the hybrid play systems classification (in Section 2.4) we could identify three core entities of a general playful system; these are the *things*, the *environment* and *people*. After distinguishing the individual entities, we defined their relationships by observing recurrent interactive aspects from the selected systems. Towards a relational modelling, we organised those into three axes relating identified core entities.

In Figure 14, things-environment axis shows what the interface elements do in the interactive environment. Environment-people axis indicates where the participants located in the environment. Then, people-things axis represents how they physically interact with interface elements, including how the I/O technologies enable such interactions.

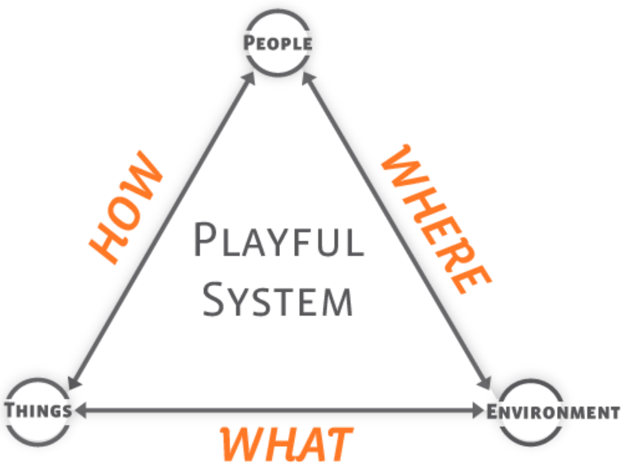

Figure 14 – The three relational axes overview presenting how, where, and what each entity relates to each other.

Things are the physical interface elements, so things are both toys and the auxiliary devices enabling interaction. Things communicate with each other using *active* and *passive* technologies. Auxiliary devices comprehend things such as computers, tablet, cameras, monitors, and controllers. We named playful things as *traditional toys*, *smart toys*, and *smart playground*. Traditional toys have no embedded technology in their design, and smart toys have electronic components. We refer as a smart playground to large installations including various connected toys.

Things related to the environment *replicating, extending, replacing, creating, destroying, updating,* and *augmenting* real and virtual information in the environment. Selecting terms allows model in describing what the interface actions in the environment. Later, we will present a playful system description using such terms.

The *environment* may be *private* or *shared* when concerning access to information. We considered access to both physical interface elements, and other environment elements (i.e. stats, scores, and items). *People* are *co-located* or *remote* located in the environment. Moreover, individuals may socially interact through *competition*, *collaboration*, or taking *parallel* actions.

People physically interact with things in four perspectives. First, a user can *visualize* things, and then, *manipulate* things or part of things. They can interact through embodiment as moving their body, or use body information (i.e. heart rate). Finally, people can *immerse* in a smart playground, by interacting with its surroundings.

The system makes use of I/O technologies enabling physical interactions. These are, displays, such as screens, LEDs, or projectors; *handheld devices*, like smartphones, tablets, and smart toys itself; *wearable* technology, including clothing, accessories, and sensors; and through connective technologies of the *Internet of Things (IoT).*

Finally, the relationships among things and the environment happen in a physical domain, and people's relations occur in a social domain. In Figure 15, we presented a graphical representation of IoT4Fun βversion de Albuquerque et al., (2016). In Table 2 we presented a summary of the model βversion relating each of the terms and their meanings.

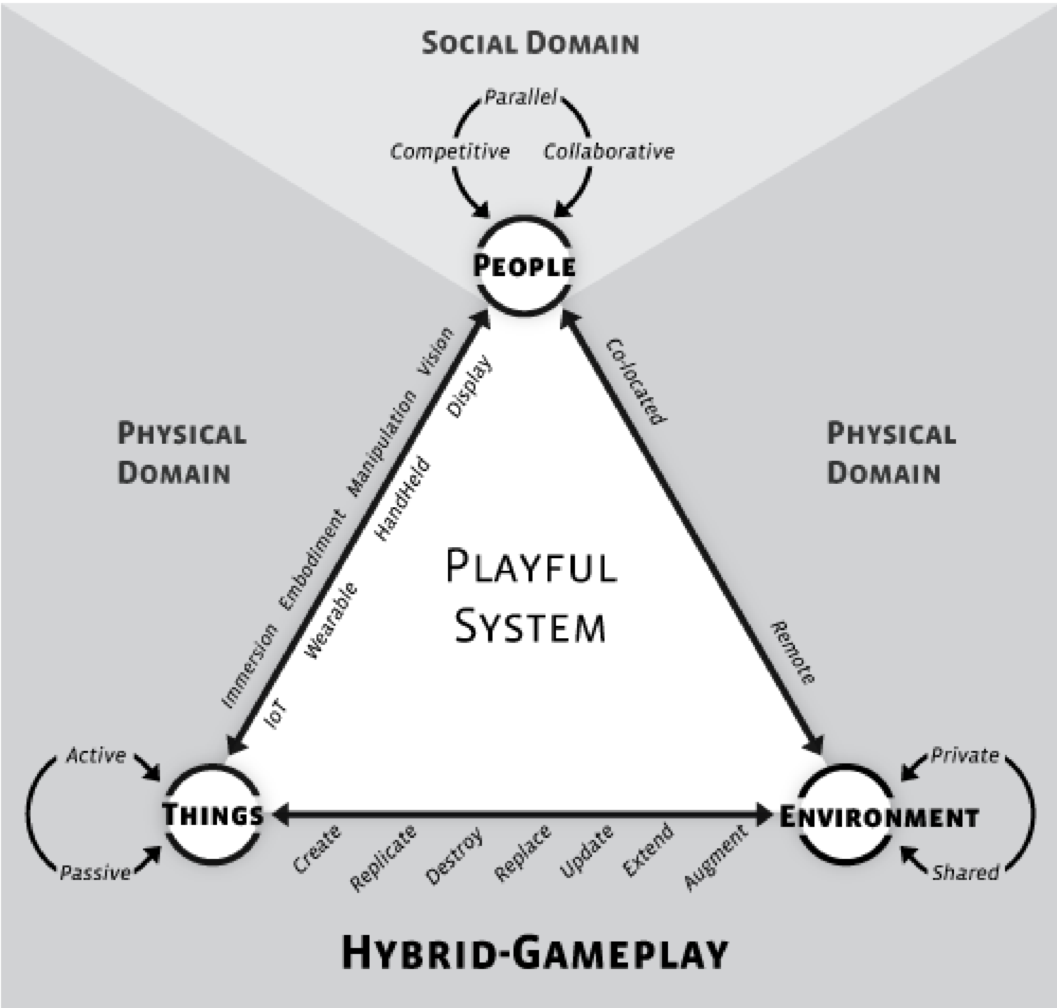

Figure 15 – IoT4Fun βversion, a relational model for hybrid-gameplay.

Table 2 – Summary of the model βversion terms and individual meanings.

Things	
Model Term	**Meaning**
Active	Active technologies comprise short and long-range connective protocols, and both embedded and external electronic components attached to things.
Passive	Passive technologies include the use of conductive materials or external cameras, the last, explore AR features and computer vision techniques such as fiducial or QR code markers, and markerless detection (i.e. colour, shape and texture).
Things and Environment	
Model Term	**Meaning**
Create	A physical game object creates new game objects in the environment, by either instantiating or creating individual pieces.
Replicate	A physical game object replicates its information in the environment (i.e positioning, orientation, and physical features).
Destroy	A physical game object destroys other game objects in the environment, by either extinguishing or acquiring those.
Replace	A physical game object replaces another game object assuming its identity in the environment.
Update	A physical game object sends its status or identity to the environment, so updating its initial state either intentionally or by interacting with other game objects.
Extend	A physical game object extends itself and its information in the environment, connecting to another game object and composing the same purpose.
Augment	A physical game object augments information non-intrusively, such as game rules, interfering in the challenge or promoting social interaction among players.
Environment	
Model Term	**Meaning**
Private	The environment is private when each player has individual access to things and/or to system information.
Shared	The shared environment consist when all players have access to things and/or system information.
Environment and People	
Model Term	**Meaning**
Co-located	People co-locate when they share a same physical environment.
Remote	People remote locate when they share system information while physically located in different environments.
People	
Model Term	**Meaning**
Competition	Social interaction modality where people compete towards the same purposes and might perform equal or different actions.
Collaboration	Social interaction modality where people collaborate towards the same goals and might perform equal or complementary actions.
Parallel	Social interaction modality where people play different or independent roles while sharing the same system and environment.
People and Things	

Model Term	Meaning
Vision	Physical interaction modality when people have visual access to things.
Manipulation	Physical interaction modality when people manipulate things or part of things.
Embodiment	Physical interaction modality when people use their body parts and movements or essential body information while interacting with things.
Immersion	Physical interaction modality when people interact with things and its surroundings, or inside larger things such as smart playgrounds.
Display	I/O technology that enables visual access through screens, projection or LEDs.
Handheld	I/O technology that supports manipulation tasks such as auxiliary devices like smartphones, tablets, and the smart toys it selves.
Wearable	I/O technology that allows either tracking body information or playful and non-playful devices attached to people's body.
IoT	I/O technology that enables interconnection among things in both long and short range.

To presenting model usage, in Figure 16, we described *Parcours* game from playful system TabletopCars Dang & André (2013). First, we started naming the physical interface things found in the system. Playful things are two radio-controlled cars and several figurines, i.e. two trees, five transit cones, and one oil bucket. The auxiliary devices are a large tabletop and a body-tracking device.

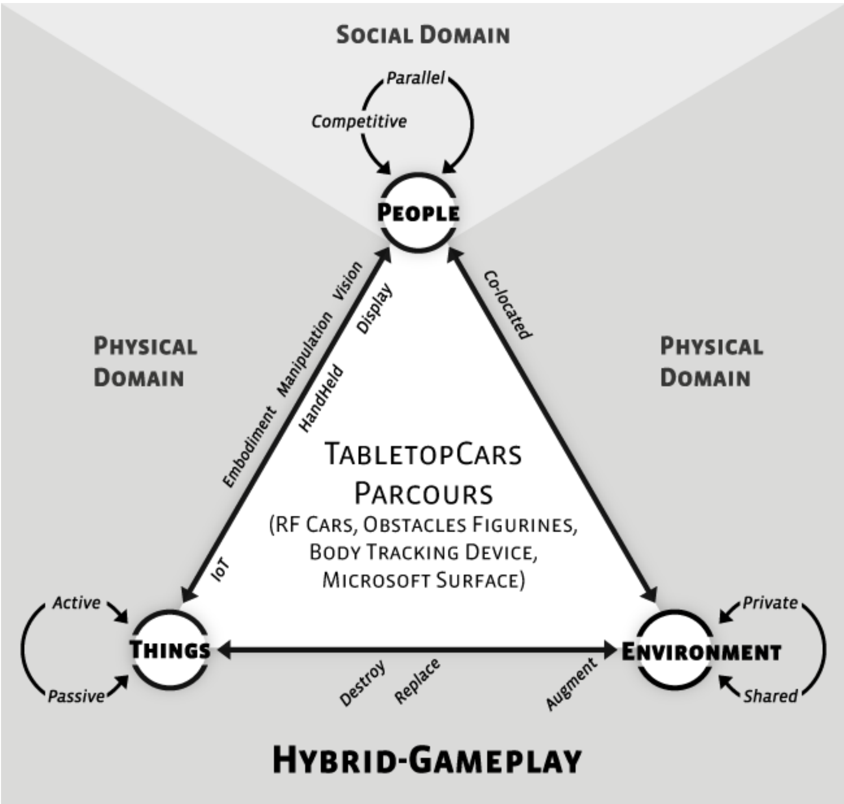

Figure 16 – Parcours hybrid gameplay described using IoT4Fun βversion.

Second, we categorised the things according to its technologies. In TabletopCars, the car figurines are smart toys, and these communicate with the body-tracking device using active RF technology. Besides, each toy car has attached an infrared marker, enabling tabletop to recognise each car's position. The remaining toy figurines use the same *passive* technology.

Third, we recognised the relationship among things and other environmental elements. Each player's cars *replace* playable functions directly interacting with virtual items in the tabletop. Similarly, the other figurines *replace* game obstacles in the environment. When the toy cars collide with any physical or virtual obstacles, it *destroys* such game objects in the environment by inactivating them. On the screen, the system *augments* car's position by presenting a virtual circle in those, also *augmenting* the level path that a player must follow, along with score points of each player.

Afterwards, we identified access to information concerning the things and other environment information. Each player had *private* access to a car while *sharing* all other interface elements. Proceeding, we recognise that people *co-locate* in such environment. Then, we distinguished social relationships among them. In *Parcours* game, two players *compete* taking *parallel* actions, which mean that each player takes a turn to a level, and *competition* occurs when comparing player's performance.

In sequence, we picked the physical interaction modalities present in the system. People *visualise* all things and *manipulate* those, such as when positioning obstacles on the screen. As players control the car movements, using their body and natural gestures, so they interact with the system through *embodiment*. Finally, we associated I/O technologies enabling the physical interactions. First, there was a tabletop *display*, which is also a *handheld device*. Moreover, things send and receive data using *IoT* technology via an RF protocol.

As demonstrated, the model βversion enables describing playful system setups in a group of interactive aspects. IoT4Fun can describe playful activities with both fixed and open rules, located either indoor or outdoor environment, including on-screen display or none. Due model synthesis aspect, it presented as an appropriate tool to define hybrid system concepts. In this sense, we decided to evaluate model βversion with students in a practical manner.

3.2 16 WEEK COURSE SCHEDULE

We taught the course in two multidisciplinary classes at *Universidade Federal de* Pernambuco (UFPE) campus. The undergraduate class, we called U1, joined 23 students from bachelor courses of Computer Engineering, Computer Science, and Design. The second class, we referred as G2, reunited eight students from a graduate program in Computer Science, including both master and doctoral degrees. Students from G2 class had experience in fields of technology, design, and publicity.

Participants from both classes declared little or no experience in developing hybrid games. However, a group of students participated in similar projects, such as 2D/3D digital games, AR applications, and Kinect games. Subjects were familiar with game engines, graphic editors, digital prototyping platforms, and 3D modelling software.

The course schedule in Figure 17 had 16 weeks, divided in 2 hours meetings twice a week. The curricula comprised initial stages of conception, ideation, idea selection, concept refinement, and low-fidelity prototyping. After these steps, students produced the first documentation. Then, we started the prototyping cycles, including playtesting sessions, and final documentation.

We evaluated the prototypes every two weeks, providing individual guidance for each project. Additionally, we performed complementary lectures and workshops of several design and technology topics. A few students along with experts led these additional activities.

In the first class, we introduced the hybrid play products field giving examples from both market and literature. During the second week, we presented the model concepts and terms, so, we conducted an exercise. For this coursework, we asked students to previous research 2-3 system examples, and then, described them using the model βversion.

Marco et al. (2012) suggested taking inspiration for hybrid games, observing how children play with both traditional and technological toys. In ideation stage, we requested to students bring toys to classes. The goal was to use them in a brainstorming session that we named *‘Brainstorm Toy’*.

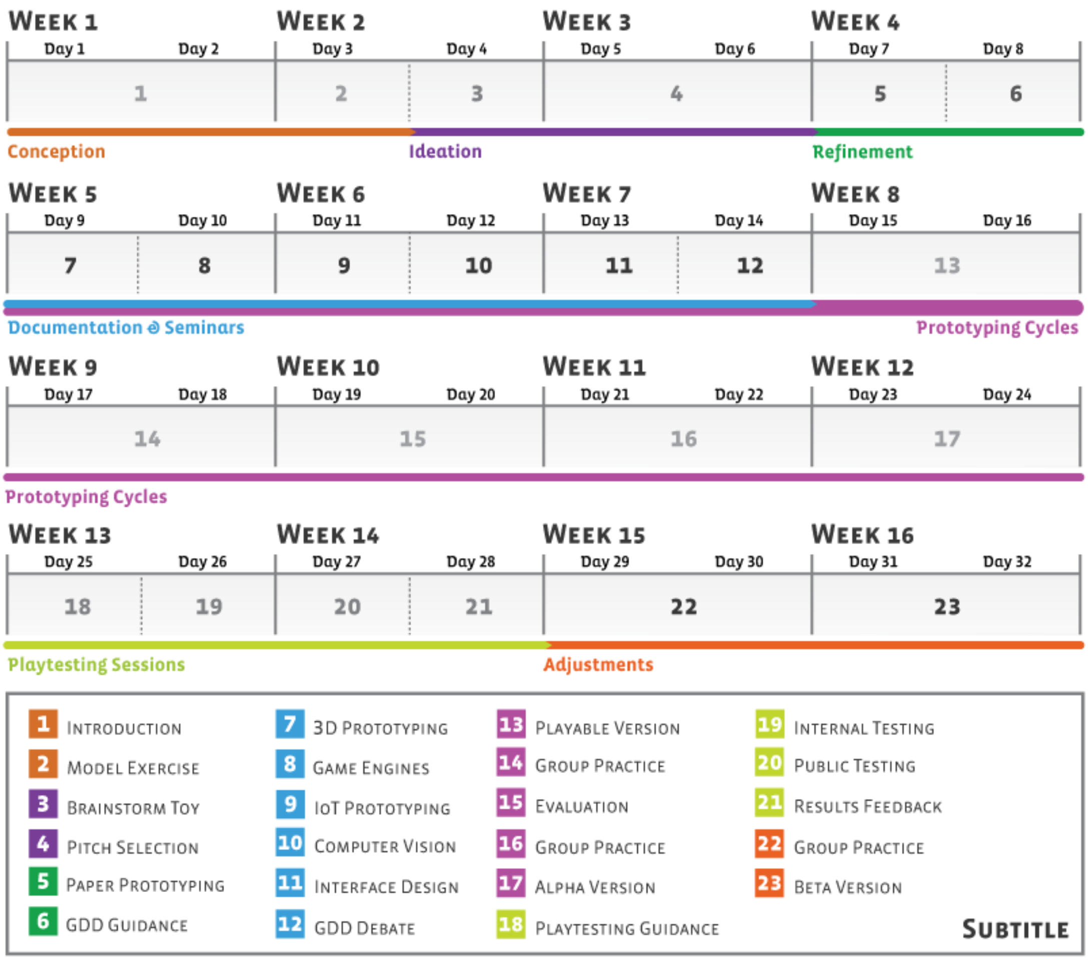

Figure 17 – A timeline of 16-week course schedule according to each stage.

We adapted Brainstorm Toy from a creative technique called Discussion 66 or Phillips 66 Denton (1999). In these, participants discussed ideas following a sequence of questions and method proposes rotating the subjects in small groups. The goal is to stimulate an exchange of views, to avoid people to fixate on a single idea. We defined a sequence of questions aiming to extract from toys both physical features and their semantic value.

- How do people play with a toy?
- What are game genres related to toy thematic?
- What the physical features of a toy?
- How to improve toy features? (Physically and computationally)
- How can a toy interact with other toys?

In brainstorming, we divided students into groups of 4-5 participants each. Then, we shared a set of toys among groups. Both the opening and closing sessions had 15 minutes, and the rotating sessions last 10 minutes each. After every rotating session, we exchanged students and available toys among groups. For the closing session, we reunited first groups to compile the ideas for selection. Thus, we asked students to select 2-3 concepts of their interest, to produce pitch presentations using the model.

Subjects used the model βversion to refine game concepts and to standardise the pitch presentations. To assist us in joining last groups, we requested students to inform their skills and abilities in an online sheet. Later in the pitch sessions, participants voted for their three favourite ideas. Besides the preference votes, we allocated students in groups based on the list of abilities. Finally, the U1 class composed four groups of 5-6 participants each, and G2 class organised two groups of four students.

At the 4th week, students refined the game concepts using paper prototyping in Figure 18. The goal of the low-fidelity prototypes was to define core game mechanics and name the physical interface elements. Before practice, we reintroduced the model, detailing its aspects, and giving examples of each term. Then, we requested students to prototype the concepts, following their selected model elements. We guided each group, and all teams prototyped playable mechanics. In consequence of this stage, students produced the first version of their Game Design Document (GDD).

We requested GDDs in two moments, the first document needed to focus on prototyping schedule, including a list of required materials, and individual tasks of each team member. Final version covered updates of game balancing, setup changings, and design improvements.

Figure 18 – Students working during paper prototyping sessions.

We provided to students a template based on the GDD structure proposed by Tim Ryam (1999)[2]. We opted to include GDDs as a class requirement, as means to organise student’s projects, also stimulating them in both planning and dividing tasks. Then, we

[2] *We made available GDD template and a editable model file in: goo.gl/Tj5wda*

used GDDs as part of the class assessment. We inserted the relational model βversion in the opening section of the document template. The goal was to keep track of groups' model description, enabling us to compare differences between first phases and final versions. This section had to contain a visual representation of prototype's model, along with a descriptive text of selected aspects.

The prototypes cycles started at the 5th week, in all stages, we supported the students in acquiring or borrowing materials. The participants requested things such as 3D prints, displays, cameras, gaming devices, and electronic components. We evaluated three versions of their functional prototypes; also, we guided students on their on-going work presentations.

The students developed their *first playable* versions implementing features of the initial GDDs. We recommended them focusing on the physical interface functional aspects, and in how to integrate the selected technologies. For the *alpha* prototypes, we required that games incorporated ending assets, playable gameplay balancing, and the interface in full operation. Students used alpha prototypes in the public playtesting sessions.

The playtesting sessions occurred in two contexts, a closed test, and an open test. Initial meetings happened in class with students and a few guests. Then, in open sessions, end-users experienced the prototypes, as presented in Figure 19. Initial tests aimed to collect technical feedback and to adjust the game setups avoiding complications during the public meetings. Public playtests had a goal to validate game experience with players, also gathering feedback from them.

Figure 19 – End-users experiencing the prototypes during the public playtests, and a group colleting feedback from users.

We taught lectures on how to conduct user testing, including how to elaborate data collection tools. Each group prepared an approach of data gathering, and we evaluated the proposed tools. Such methods included pre and post testing questionnaires, semi-structured interviews, and individual or collective evaluations.

Afterwards, the students presented test results in class. Thus, each group listed points for future improvement in the *beta* versions. Our last assessment concerned the student's beta prototypes along with their updated GDDs. Students also produced a closing presentation, including a demo video of gameplay prototype.

Following, we divided the coursework results into two sub-sections; first, we present how students used the model βversion in initial design stages. Second, we show the results on prototyping cycles, including student's outcomes of the playtesting sessions.

3.2.1 Modelling Student's Concepts

The initial stages of course schedule were conception, ideation, and documentation. In the conception stage, students used model βversion in a practical exercise of describing existing systems. Altogether, the subjects produced 50 practice sheets, so, U1 class made 37 sheets, and G2, 13. Then, in training, students described 35 single cases, so, 26 sheets presented 11 repeated systems. Among replicated cases were *Pokémon Go* Niantic (2016)*, Cubbeto* Primo Toys (2013)*, Talkie* Toymail (2016)*, Amiibo* Nintendo (2014)*, BB8* Sphero (2015)*,* and *Cognitoys* Cognitoys (2015).

During the brainstorming session, students generated 15 ideas in U1 class, and 10 ideas in G2 class. Participants described the original concepts in a single sentence, or in a sequence of references. For concept selection, students presented 13 pitch ideas in U1 class, and 6 concepts in G2. All presentations consisted of 4-6 slides, introducing an idea using the model βversion and its aspects. Students presented what were the things, other setup elements, a few topics and related images, along with a figure of their concept model. After the preferential voting, students selected six of the game ideas.

Students from the U1 class named their four concepts as *Cubica*, *BUD Monster, Forecastle*, and *Legends of the World*, and G2 students selected two ideas entitled *Stormstone* and *Undercroft*. The students modelled their six concepts while preparing the pitch presentations, and in both initial and final versions of their documents.

The first GDDs had 4-8 pages divided into five main sections with several subsections. These were an introduction including the conceptual model, tasks schedule, the required materials and components, core game mechanics, and the user interface elements. The final version of GDDs had 30-70 pages, and these incorporated updates of the first GDD sections, along with corresponding content. The additional sections referred to arts and design assets, audio content, a summary of prototype versions, and user testing reports.

In sequence, we detailed two of the student's models according to records in their final documents. A description of the four remaining prototypes using the model βversion is available in Appendix B. Results reflected how students experienced the model in classes. Then, to presenting each prototype aspects in this thesis, we adapted and translated text fragments of the student's GDDs. Moreover, since using the model was an interpretative process we recognised aspects that required adjustments.

Cubica in (Figure 20 and Figure 21) is a hybrid puzzle with a turn-based battle system. Two *co-located* players *compete* as wizards, guiding mystic creatures using passive *handheld devices*. Then, each player *manipulates* a *private* Rubik's cube, and both players *visualise* virtual game objects through a *shared* monitor *display*.

To *activate* game actions, players must arrange a single cube's face following *required* colour combos. A webcam captures the cube's face after players positioning it in a *passive* fixed base. When the system recognises a potent combo, the cubes *extend* player's in-game actions.

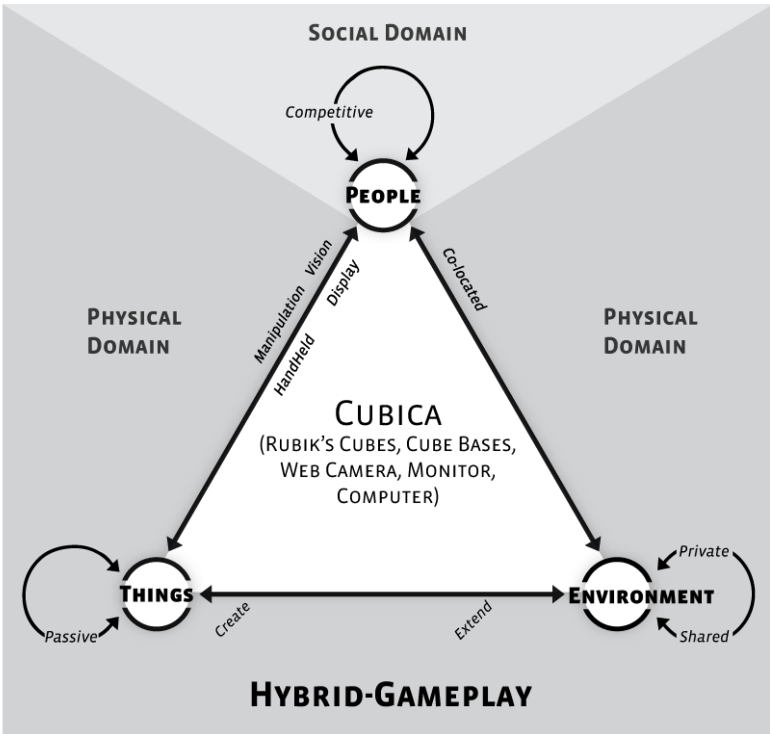

Figure 20 – Student's model βversion for Cubica hybrid gameplay.

Figure 21 – Cubica: a) a customized Rubik's cube in a passive base, b) players engaging their cubes in a turn, and c) a shared virtual interface.

Each action is analogous to a single colour, so, the system can distinguish the cube faces through its central coloured square. The colours and its corresponding actions are: blue to move characters, red to melee attack, orange to ranged attack, white for special attack, green to activate shield, and yellow to energy recharge.

Besides colour, players need to arrange combos to complete actions. For example, to move a creature, a player selects the face with the blue central square. A user must arrange an adjacent blue square, to indicate movement's direction. When players activate valid combos, the cube *creates* game elements on-screen.

Players may choose among three creatures of similar skills and strengths. In addition to combats, characters can suffer damage through dynamic thorns appearing on the arena. Wins a player, which defeats an opponent first.

Undercroft in (Figure 22 and Figure 23) is a hybrid arcade game inspired by the Hole in the Wall television game show. The game world is *private*, consisting of a dungeon full of virtual obstacles, as moving walls and traps. Player *visually* accesses the game through an on-screen *display* and *manipulating* a *passive* articulated toy.

The goal is to *create* poses using the toy that matches with silhouettes of the moving walls. The player *manipulates* the toy articulating its body, arms, and legs on an *active* board. The articulated toy has magnets located on its foot, enabling it to stand-up on the game board surface.

A webcam positioned on the game board terminal captures the toy's outline in each round; hence, the system identifies through media, a solid match. The *active* board *extends* all game elements off-screen then game scenario comprises both virtual and real scenarios. Board has a 10 LEDs representing virtual items and *updating* their proximity. LED colours will vary as a warning sequence, in green to yellow, and red. The smart board has a motor mechanism to open a trapdoor; hence, if a player loses all health points, the toy falls into the trap.

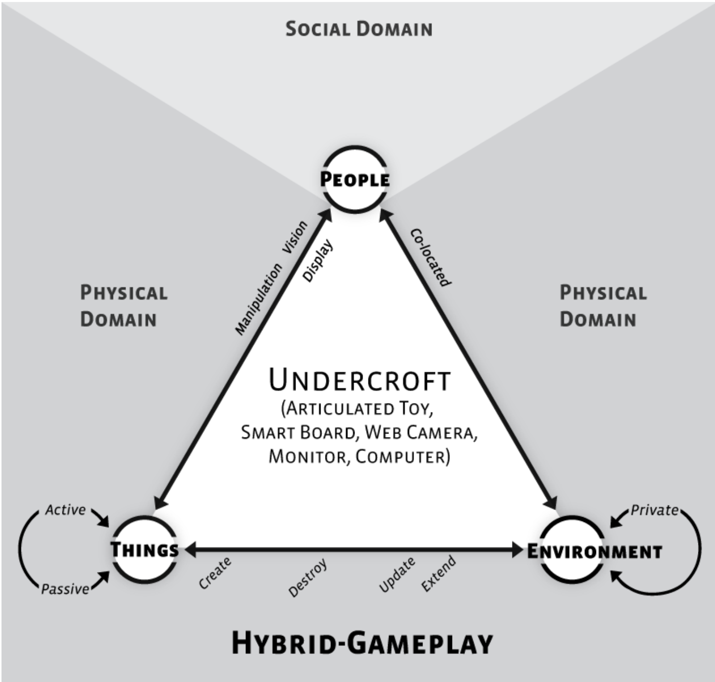

Figure 22 – Student's model βversion for Undercroft hybrid gameplay.

Figure 23 – Undercroft: a) the toy in a correct silhouette, b) LEDs augmenting wall position, c) a losing level feedback, d) the toy catching an extended power-up, and e) a player manipulating the toy on the active board.

Regarding game elements, the *extended* moving walls are analogous to elements of Nature, like water, fire, wood, and stone. A player can collect *extended* power-ups, so, the user must position any part of the toy inside a range, where a desired item appears. For example, if a power-up comes from the upper-left corner of the screen, a player may *create* a pose enabling the toy's arms to reach it. When a player catches a game element, the player *destroys* it in the environment.

Such items can confer either defensive or offensive power, and a user can store a single item of each type at a time. To activate them, the user presses buttons located on the board, *creating* corresponding game elements on-screen. The four buttons set includes directional arrows, to make the character jump and crouch avoiding virtual traps. A player succeeds by passing through all levels and obstacles, or fails if he/she loses all HP.

Following, we discuss the student's outcomes using both objective and subjective analysis. Students used the relational model in stages of conception, idea selection, and documentation. Starting with conception, when completing exercise sheets, several students requested advice to selecting the model terms. Considering that the students accessed general information of systems through images, videos, and text, they used limited data on both interface and gameplay.

In overall, they were able to select the system interactive aspects. However, analysing the replicated system sheets, we found inconsistency among student's interpretations, especially on the things-environment axis. Inconsistency means that participants had selected different elements to describe the same systems. We expected this since model usage was interpretative, and that things-environment was the model axis containing original terms and concepts.

Students had difficulty in selecting aspects of the people-environment axis in a single-player system. Moreover, several participants made mistakes when choosing terms from people-things axis due its aspects comprehend two columns. For example, they selected *'display'* as an I/O technology, without, picking *'vision'* as a physical interaction. Similarly happened to *'manipulation'* and *'handheld'*, despite both terms are not inherent, they tend to appear together in many systems.

Participants described and improved their concepts using the model βversion during the pitch selection. For this step, students got access to class materials, and they consulted the presentation slides; also, we distributed hard copies of the model's article Albuquerque et al., 2016. Using the supporting material, students described their ideas in the model. For example, participants managed to select aspects of the people-things axis since they could distinguish the terms of two columns.

After this stage, students required no assistance in choosing both I/O technologies, and the physical interactions modalities. Moreover, several students started using the model centre to name the things present in their systems. Still, we noticed issues in the things-environment aspects, but this time recurrent mistakes related to students omitting some existing elements. The *Undercroft* conceptual model presented the selected aspects of *'create'*, *'destroy'*, and *'updated'*, and despite the system *'augment'* data on the game board, students omitted this term.

Furthermore, we could recognise design changes among the projects, by comparing how students described their models in the initial and final versions of GDDs. Initial concepts predicted more interactive aspects than the final versions. Several conceptual models involved multiplayer modes, and a large number of physical interface elements. *Undercroft* team expected to build two smart boards to promote competitive and collaborative game modes, later, they produced a single-player system. Initially, the LEDs on the smart board replicated the walls movements. In the final version, they opted to extend the walls through the LEDs, duplicating the available gaming area.

Regarding the quality of model's description, these were equivalent in both versions. However, the last GDDs were larger documents, they included projects adjustments, and during the GDDs updates, some groups made mistakes. *BUD Monster* team selected the adequate aspects 'replicate', 'destroy', and 'update' in the initial GDDs. In the last GDD, they omitted 'destroy' aspect, and exchanged 'replicate' to 'replace', despite the monster glove replicate on-screen. Although, similar mistakes do not appear in *Cubica* since their prototypes had minimal changes from the concept to *beta* versions.

3.2.2 Prototyping Cycles and Playtesting Sessions

Prototyping cycles comprised four main stages, including ongoing presentations within each step. The first version was the paper prototypes in this juncture groups focused on the core game mechanics and the system interface elements. The paper prototypes were necessary to defining the essential game design decisions and the interface I/O elements. Team *Cubica* defined a grid map and basic interface aspects, such as how to use the cube to move characters and to release attacks. These initial decisions grounded mechanics to other game actions in the functional prototypes.

Other three stages were the working prototypes; the *first playable* version required primary interface aspects and its technologies integrated into the core gameplay. In G2 class, the *Undercroft* presented the active board game, containing LEDs combined to virtual obstacles, and the 3D printed articulated toy, but they did not implement colour detection.

Afterwards, we required that *alpha* prototypes have the interface in full operation and a playable gameplay balancing. They also had to incorporate finished assets, including animation of virtual elements, graphical user interface, and visual identity. Final prototypes, or beta versions, were similar to their alpha prototypes, but including design improvements in consequence of the user testing results.

During prototyping cycles, all working versions incorporated improvements and the adjustments followed two main reasons. First, aspects related to planning and development challenges, second, in response to feedbacks of both on-going presentations and the user testing. The *BUD Monster* concept planned four wearables these were a pair of gloves and two monster caps, each one representing a character. The idea was enabling users to exchange characters wearing different costumes. However, they implemented a single working glove in time.

Concerning development issues, the *Forecastle* team replaced a projector and physical map with an on-screen display. This due the projector emitted light that was interfering colour tracking of the boats on the map. Several prototypes exchange their physical interface materials. *Stormstone* conductive touchpoints used paper foil, magnets, and copper wire. Finally, they replaced the 3D prints with metallic figurines using insulation tape.

Modifications promoted by user feedbacks, related to how the system presented information in both graphical and tangible interfaces. Such improvements were changing the position of visual elements, replacing pictograms of icons, and resizing text content.

The public playtesting occurred in two sessions, and both events received about 25-35 users a day. Altogether, students gathered individual feedback on 106 playtests, and at least, each prototype had collected feedback from 10 players, plus three games have reached more than 20 users. Some testers repeated the same games, and have appeared in both playtesting sessions. Users pointed aspects on fun experience, engagement level, game balancing flaws, and interface features.

Due technical issues a few prototypes performed partial or adapted functionalities. Both *Undercroft* and board game *Forecastle* that used computer vision techniques found issues on environment lighting. The *Undercroft* tested their prototype outside the event, and *Forecastle* exchanged a projector by a monitor. Despite practical problems, students of both classes produced playable prototypes.

During tests, students gathered feedback from players using different data collection tools. Several groups used a demographic questionnaire to assess player's profile, such as their game preferences. Playtesting sessions enabled to assess fun experience promoted by each prototype. Table 3 shows a summary of the group's playtesting results and their chosen gathering approach.

Table 3 – A summary of playtesting results of each group.

Group's Prototype	Gathering Method	Number of Testers	Summary of Results
Cubica	20 minutes post testing semi-structured interviews and an additional 1-5 Likert-scale questionnaire with eight criteria: character design, thematic, gameplay experience, games rules comprehension, interface design, turn duration, match duration, and fun experience.	29 users	Qualitative summary: Users enjoyed both character design and the game cube mechanics. The prototype required adjustments in the feedback of character's energy recharge and status, a better distinction among character's special powers, message for a matching tie, and feedback of the colour game rules in the physical cube. Quantitative summary: 25 players pointed 5 in the fun criteria and four remaining selected a 4. 16 users pointed 5 to interface design, and 9 scored a 4. 18 players pointed 5 to character design and thematic. The turn duration score presented eight people scoring both 2 and 5, while 13 among 3-4. 24 users selected 3-4 for overall match duration. 15 users pointed 5 to the gameplay experience, and 11 scored a 4. 12 people scored 4 to game rules comprehension, and seven users scored both 5 and 3 to the same criteria. None of the users pointed 1 to any standards.
BUD Monster	Gameplay video recording, along with a post testing unstructured interview aiming immediate feedback of gameplay experience, and an additional 1-5 Likert-scale questionnaire focused on user's profile and rating points on game experience.	15 users	Profile summary: 80% males who are high-engaged players interested in adventure & action, and RPG genres. Gameplay rate (average varying from 1-5): 3.9 to a quick match duration, 2.7 for interesting narrative dialogues, 3.3 for the controlling interface performance, and 1.8 for the perception of physical effort. Qualitative summary: Not all players experienced the special attacks. Users kept destroying buildings after the game has ended, and they ignored the available "good monster path" (reducing the number of enemies spawn by destroying fewer buildings on the map). They enjoyed wearing the glove and felt immersed in the game. The narrative little influenced in gameplay, and players followed the level goals also performing free destructive game actions. Required adjustments: improvements in the GUI messages, adding an HP recovery function, new visual elements to recall narrative in the game map, and implementing a game tutorial before the match.
Forecastle	A pre-test and post-test questionnaire. Pre-test focused on player's profile, and a semiotic test for the GUI icons meanings. Post-test aimed to assess gameplay	24 users responded the pre-test and nine players the post-test.	Pre-test summary: 58% were high interested players and 25% were moderated players. Great interesting in action, adventure, strategy, and RPG games. 87% had an active interest with game thematic. Users identified a low assimilation of the mystery event icon. Post-test summary: All players understood the game goals. Six people marked as regular the

	experience, game mechanics and dynamics.		match duration. 88% would like to play again; seven people evaluated with a low score the number of enemies and dangerous interactions. Players pointed 4 and 5 to the understanding of game rules, and a regular score concerning the available resources. Required adjustments: Decrease the number of resources to stimulate map section exploration and other game actions. Increase the number of dangerous events, and stimulate player vs player combat.
Legends of the World	Gameplay video recording, along with a post-test questionnaire focused on player's profile, and topics on the gameplay experience, game mechanics and dynamics. The questionnaire included both a 1-5 Likert-scale and open questions.	22 users	Likert-Scale questions summary: 90% of players approved interface design, and presented little or no difficulty in manipulating the figurines. All players scored among 4-5 on fun experience, 90% of them would like to play it again, and 95% would recommend the game to a friend. Players were majority male and had a high to moderate interesting in games, with preference on action & adventure, and RPG genres. Open-questions summary: Some players had difficulty in finding the tablet's NFC reader. All players found the size of figurines adequate. A few people presented struggle in understanding the advantage & disadvantage mechanics. The players approved the turn match mechanics, and they found the positioning in battle system innovative and fun. Required adjustments: setting a fixed place to positioning the NFC tags inside the cards, improvements in GUI and feedback of power's cooldown. Adjustments in the cards to make clear the advantage & disadvantage mechanics.
Undercroft	Gameplay video recording, along with two pre-tests and one post-test questionnaire. Pre-tests first focused on player's profile, and second on a semiotic evaluation. Post-testing aimed to assess gameplay information, including 1-5 Likert-scale and open questions.	10 users	Player's profile: all male ageing from 18-29 years plus two under-aged players. High interest in FPS, action & adventure, car racing, strategy, and RPG genres. A moderate to strong interesting in games, with a preference towards a challenging game experience. Interface design aspects: Regular to great challenging in manipulating the toy interface, and 50% of people found hard to create a pose. All players understood and approved icons from both GUI and TUI. 75% approved the LED feedback on the game board, and they interpreted as either proximity or reverse counting. 66% found easy to capture power-ups using the toy. Gameplay assessment: 83% rated 4 in fun experience, and 41% scored a moderate challenge. 75% understood game rules, and others had a few concerns. Some players felt frustrated when failing in either clashing a wall or falling into the trap door. Also, the jump

			interaction presented a delay. Required adjustments: decrease the speed of wall's movement, and improve the balance of numbering of items and virtual obstacles.
Stormstone RPG	Gameplay video recording, along with a pre-test on user's profile, and a post-test questionnaire with 1-5 Likert-scale and open questions focused on the gameplay experience.	21 users responded the pre-test, and 17 players responded the post-test.	Player's profile: 19 male (plus two female) with great interesting in games and electronics, and preference for action & adventure, strategy, and RPG genres. Likert-scale questions summary: 16 players scored 4-5 in overall satisfaction and 15 on game dynamics. 15 user also found interface easy to use, and 11 of them voted as 'extremely easy'. 9 (most of) participants voted three on the game challenge, and 3 pointed it as 1 (very easy). Open questions summary: 16 players voted game as fun, and they would recommend it to a friend. Players requested more implemented game actions, obstacles, and characters, also asking improvements on GUI information. Required adjustments: implementing the obstacles system; feedback for the death action (virtual blood splashed on-screen); and re-size of character's HUD and other minor GUI improvements.

Later, students presented the test results in class, and their presentations showed a list of proposed improvements. Prototypes core game mechanics led to fun experiences for players since the test reports submitted positive evaluations on this topic in all six prototypes. In that way, the prototypes presented effective results on short-engagement experiences, and we believe that design improvements might add benefits to long-term matters. We evaluated their presentations and helped them in selecting adjustments for their *beta* versions. Additionally, students produced playtesting reports to incorporate in their last GDDs.

Students were successful in creating meaningful interface elements that incorporated both interactive and semantic values. *Cubica* proposed a puzzle battle, where both mechanics and strategies, turned the toy fundamental to interaction. The *Undercroft* team created a level design based on the physical features of an articulated toy. Then, to define virtual wall silhouettes, they had to take pictures of the toy in several poses. Also, the active board extended the game environment, and it duplicated available gaming area. We believe that such decisions were a consequence of model βversion usage in early development stages. Aiming to address this assumption, and to assess model usefulness, we interviewed the students after classes.

3.3 ASSESSING MODEL USEFULNESS

Following a qualitative approach, we conducted semi-structured interviews with student's representatives of each group after passed one month from the classes. The goal was to assess model usefulness in several stages of the creative process through a subjective evaluation.

We selected the participants consulting GDDs revision history, identifying which of the students described their prototypes in the documentation. Then, we emailed them to schedule the interviews, also asking students to confirm their part or to suggest another representative. Moreover, we recorded all interviews to transcription, and we performed free translation from Portuguese to English. We used an open and axial coding procedure to analyse data on texts, enabling us to point out topics and similar views among the participants.

In

We conducted seven semi-structured interviews with at least one student of each group, and the interviews lasted 10-15 minutes. During transcription, we attributed codes for the participants to ensure anonymity, and we referred to subjects in this thesis using acronyms (i.e., joining class code with a capital letter).

According to gather, the model βversion was useful in describing the student's prototypes. For example, participant U1A mentioned how *model helped their group in determining game characteristics.* Similarly, U1C claimed that the model assisted in describing their project since *it was easy to visualise game aspects using its terms.* For interviewers, using the model facilitated in both describing and in understanding game setup. As G2G elucidated, *"the model helps you to define game setup."*

Subject G2F commented that through the model was *possible to visualise setup complexity while recognising the number of selected aspects in the 'triangle'*. Subject asserted that the model assisted in project planning such as *cutting off elements and selecting both possible and essential aspects.* Analogously, U1D said, *"*Initially*, we wanted to choose every aspect of the model, then, during development, we could know what elements supposed to stay, and which of them we could remove."*

, we established a semi-structured interview script in 11 main questions along with auxiliary questions, or probes, to aid in collecting hidden data. We defined the script aiming to assess how students comprehended and experienced model and its terms. We also elaborated questions on other course methods, such as the Brainstorm Toy, paper prototyping, documentation, and playtesting sessions. Our goal was to distinguish the model usefulness from the other course resources.

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Table 4 – Interview script to assess model usefulness.

Main Question	Auxiliary Probes
Did you ever experience hybrid games before the course?	If so, what experience did you have? Did you play a hybrid game? If so, which game it was? Did you develop a similar game? If so, can you describe it?
Did you and your group, consulted any material to define your prototype model?	If so, which of available materials did you use? Have you used class presentations? Did you read the model article or any part of it?
What do you think about model concepts?	Were the concepts descriptions clear to you? Did you find any difficulty to understand them? If so, which parts were difficult to you? Could you differentiate meanings of model's terms? Is there any point of the model that made you confused?
Did you think theoretical classes helped in conceiving your group's project?	--
Did you think model helped in any step of your project?	If so, did model helped you to improve your group's idea? Was it useful in the documentation? Would model assisted in choosing prototype technologies? Would model contributed to defining game interactions?
Which steps among classes did you think helped your project?	What do you think of brainstorming session? What do you feel of paper prototyping? What do you think about playtesting sessions? Could you differentiate feedbacks of closed tests from public meetings? Did you find class guidance was helpful to your project? Did you think was useful to discuss with other group members? What do you think of game design

	documentation? Could you distinguish initial and final documents?
Can you recall any terms of the model?	If so, what terms do you recall?
Did you think model terms helped you to communicate with your group?	--
Did you think model terms helped you to understand other group projects?	--
What have you understood on active and passive technology?	--
Do you intend to design hybrid games after class?	Is there anything else you want us to know?

According to students, the model helped them during the initial stages of development. For example, participant G2F recognised the *model as a fundamental tool to define hybrid game concepts.* Thus, subject U1E declared that the *model aided in defining system requirements, before implementing the game functions.*

Subject U1B commented on the things-environment axis decisions, *"it was good because we had trouble while choosing extension or replication, then using the model we could select one of those".* Similarly, both U1C and G2G mentioned how the things-environment axis assisted their group *in establishing game mechanics.*

Students incorporated the model vocabulary, and during interviews, they used model's terms when commenting on their projects. According to participants, the terms *facilitated* the intergroup communication. For example, U1B claimed, *"Since all students knew the vocabulary, made easy to use the terms than formulating larger sentences to describe what the interface elements would do in the system."*

Analogously, U1C commented on the term 'extend', *"Just in mentioning the term 'extend', someone would ask, where it will extend. Will it use a screen? Will it use a projector?"* Interviewees claimed that the vocabulary helped them to understand other group's projects. For example, U1E said that *when visualising other team's 'triangle' was possible to name what they were developing.* The student G2F alleged that *terms were useful while talking to other teams, as on comparing how they implemented similar aspects in their projects.*

When we asked on model usage in the GDDs, several students mentioned its *relevance* in the first documentation. They stated the model usefulness to both describe and visualise the system aspects. Interviewer G2F thought the model synthesis so useful, that subject suggested us *creating similar mechanisms for the complete documentation.*

Furthermore, students cited other course resources in the interviews; these were the *Brainstorm* Toy, paper prototyping, and playtesting sessions. Participants appreciated both brainstorming dynamics and the pitch selection. They considered the paper prototyping a good practice to define initial requirements of their games.

Subject U1D commented on the course schedule, *“I really liked pitch presentations, as in using toys to generate ideas, also, I've enjoyed paper prototyping practice. The theoretical part was very important, but the practical stages were better. I found great that happened several playtesting sessions during the course schedule.”* Moreover, the students asserted on technology and design lectures, distinguishing topics on game engines, computer vision, and concept art.

Based *on* student’s outcomes, we could distinguish the model usefulness along course schedule, and the model had an impact on initial design stages. However, the model βversion usage presented several issues for the participants. Hence, in the next section, we will show how we used student’s feedback to improve the *IoT4Fun relational model* nomenclature and structure.

4 IOT4FUN FINAL VERSION & EVALUATION

Based on the interview results, we could recognise points of the model βversion that *required* adjustments. In the present section, we started presenting how we modified the model structure using the student's feedbacks. Then, in Section 4.1**,** we detailed the model final version presenting each entity and their related concepts. Later in Section 4.2, we modelled four existing systems using the IoT4Fun model. We also used the model as a classification tool to describe other 16 playful systems that are available in Appendix C. Aiming to evaluate changings, in Section 4.3 we showed results of three creative workshops using our proposed model.

Overall, using the model βversion, students comprehended the three entities and their relationships; it is the things, people, and the environment. Participants could distinguish passive from active technologies, access to information, and social interaction modalities. Despite, in their first contact with the model, students presented struggle to understand the people-things axis, due it presented aspects displayed in two columns.

When experiencing the model through the course, they could differentiate the physical interactions from types of I/O technologies. For example, subject G2F commented that *had difficulty in understanding such aspects since it seemed similar*. However, after consulting class materials, the participant stated as *"clear"* the distinction among groups of aspects, and the same process happened with other four interviewed subjects.

Concerning the people-environment axis, students presented difficulty in locating a person in a single-player system. In consequence, participants felt confused when selecting the social interaction aspects of such systems. Interviewer U1B commented that their team implemented a single-player game, and they *found issues since the model only presented multiplayer aspects.*

Regarding the things-environment axis, students referred to the aspects definitions as *"clear"*, *"intuitive", "easy to learn",* and *"concise"*. However, several participants presented issues in selecting the model's terms. The recurrent aspects that caused mistakes for the students were 'update', 'destroy', and 'augment'. For example, subject U1D commented on the 'destroy' term, *"At first, I did not understand if destroy was related to extinguishing an object entirely, or it would apply to a simple game instance. But, after seen it implemented in other prototypes, it helped me to understand its meaning".*

Several students alleged that examples of the aspects in existing systems assisted them in differentiate the model concepts. When G2G referred to the first model exercise, *"During exercise, where you showed several examples of existing systems, it helped a lot in understanding the concepts."* The participant U1C claimed, *"Yes, the main resource was the examples. Using the examples was easy to know what to do or not, and if our game had an aspect or not".* Interviewer U1D mentioned that in addition to the article's information, the *visual material with examples was very elucidative and important.* According to students, visualising existing systems clarified the model aspects meanings.

To address the student's issues, we promoted adjustments in all three axes of the model. In Figure 24 we highlighted the changings comparing βversion and the model final version. Starting with the people-things axis, we replaced the term *'immersion'* with *'pervasiveness'* since the word 'immersion' incorporated multiple aspects on game experience. For example, the BUD Monster team selected *'immersion'* in their model, despite their interpretation contrasted the aspect's meaning. Our goal was to select a term to represent systems where people interact with things and its surrounds, such as in smart playgrounds. We considered the term *'pervasiveness'* appropriated to describe the disruptive concept of such systems.

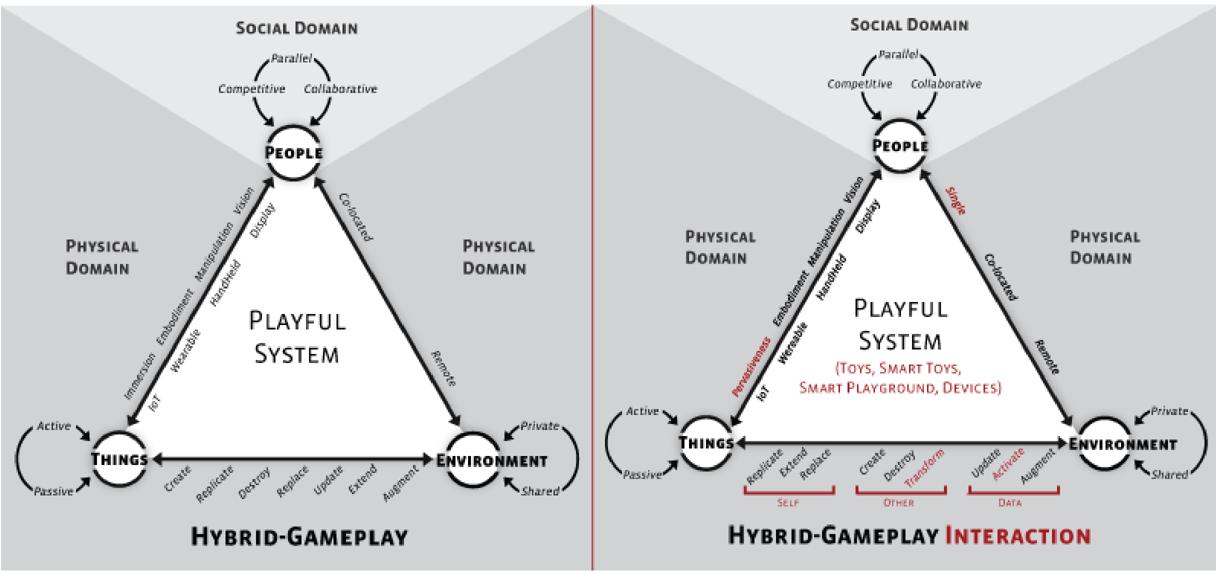

Figure 24 – Red colour highlights changings between model versions.

Observing student's prototypes, we noticed that current terms were missing a few interactive aspects. In the people-environment axis, we included the term *'single'* to describe systems with one player, representing systems without social interaction among people. Then, in things-environment axis, we added two new terms; first, we included 'activate' to represent when things send/receive a single action to the environment. In *Undercroft*, 'activate' would describe actions where a user presses a button on the game board. The user would both activate power-ups and activate character's movement functions. Furthermore, we inserted 'transform' to represent when things change an existing game object in the environment. *Cubica*'s cube would transform the position of creatures during gameplay.

Afterwards, we organised all nine interactive aspects into three groups named *self*, *other* and *data*. Then, we named the *sort of things* inside the model, to stimulate users in describing their setup elements using it. Also, we inserted the term *'interaction'* on the title, to make clear that the model describes relationships involving the physical elements, instead of the entire gameplay. Coming next, we detailed the final version of IoT4Fun, a relational model for hybrid gameplay interaction.

4.1 A RELATIONAL MODEL FOR HYBRID GAMEPLAY INTERACTION

IoT4Fun relational model describes playful systems relating three entities: the *things*, *environment*, and *people*. Each relation axis represents a group of interactive aspects between two entities. Besides axes, each entity relates to itself. The things and environment axis show *what* the interface elements do in the game environment. Environment and people axis indicate *where* the participants locate in the environment. Then, people and things axis represent *how* they physically interact with the interface elements, including *how* I/O technologies enable such interactions.

4.1.1 Things

Things are the physical interface elements, so, things are both playful and non-playful things. Therefore, things are toys and the auxiliary devices enabling interaction. We presented system's things in the centre of the model, allowing visualising the overall setup elements.

Based on their technological features, we named three sorts of playful things; these are the *traditional toys*, *smart toys*, and *smart playground*. Traditional toys do not present technology in their design, such as the plush-toy *DiDi* Warren (2014) and its food touchpoints toys. Smart toys have embedded electronic components, such as the toy-robot *BB8* Sphero (2015). Smart playground refers to large installations including various connected toys, such as the *Playmation* wearable-toys and smart figurines Hasbro

(2015). *Auxiliary devices* comprehend non-playful things such as computers, tablet, cameras, monitors, and controllers.

In Figure 25, things communicate with each other using *active* and *passive* technologies. Embedded active technologies allow things to receive, sending and recording data. Passive technologies enable data transfer using an external device, such as a digital camera able to record media on things; hence, a software using a computer vision algorithm may support detection from the media channel. Smart toys using connection protocols such as BLE, NFC or RFID make use of active technologies. Traditional toys using either touchpoints, AR markers (i.e., fiducial markers and QR codes), or allowing markerless detection (i.e., colour and texture detection) make use of passive technologies.

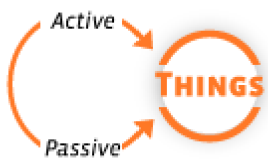

Figure 25 – How things may communicate in the model.

4.1.2 Things and Environment

According to the model, things and the environment relate in three perspectives: through a self-representation, by interacting with other game objects, and either sending or receiving data. Following, we assembled interactive aspects in three correspondent groups, listed as *self*, *other*, and *data*.

SELF-group in Figure 26 includes different ways that a physical game object can *self-represent* in the interactive environment. In Figure 27 the things can self-represent in three ways: *replicating*, *extending* or *replacing* a game object.

Figure 26 – SELF-group in the things-environment axes.

Figure 27 – Three self-representation of a physical game object: a) Portico spaceship replicated on game screen, b) a player wearing Ironman gear extending shooting towards a smart figurine, and c) building blocks replacing a tower bridge in Magikbee. Adapted from: Avrahami et al. (2011), www.playmation.com, www.magikbee.com

Replicate refers when a physical game object replicates its information in the game environment. Such information includes physical features such as colour, shape, and texture, and its relative data, such as position and orientation. Despite the things presenting two formats of self-representation, both physical and replicated game objects are the same. Portico platform Avrahami et al. (2011) presented a space-themed game, where a spaceship toy replicates its physical features in a virtual game object. In ChillFish Sonne & Jensen (2016), when a user exhales into fish-toy, it will make the replica swimming up, when inhaled, the fish swims down.

Extend indicates when a physical game object extends itself in the game environment while connected to another game object. A game object can extend its information such as direction and trajectory, including its physical features. Different than replicate, an extended object is self-represented in two distinct game objects; however, these are both connected and inherent to each other. Rope Revolution Yao et al. (2011) presented a game where a physical rope extends itself connected to a virtual kite. A player controlling the physical game object can control the kite's flight and movements. Another example is Lighthouse Bakker et al. (2008), where a smart toy extends its light in the environment, so, extending the light direction enables the toy to detect the player's position.

Replace means when a physical game object replaces another game object assuming its representation and information in the game environment. In this sense, replacement feature enables a physical object directly interact with other game objects. A replaced game object is a single self-representation of two connected and inherent game objects. In Fuzzy Flyers (2016), when children play the 'egg toss' game, a plush bird toy replaces the 'egg' assimilating the game object information such as speed and relative position. Similar appeared in *Magikbee* Magikbee (2016) when a player places building blocks on a tablet screen; those replace a bridge and its game object functions, allowing the virtual characters to crossing it during the level.

OTHER-group in Figure 28 comprises the different ways that a physical game object can interact with other game objects in the interactive environment. In Figure 29, the things can either *create*, *destroy*, or *transforming* other game objects.

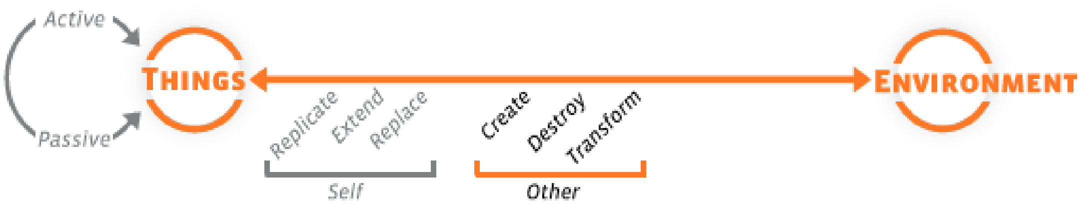

Figure 28 – OTHER-group in the things-environment axes.

Figure 29 – Physical game objects interacting with other game objects: a) players creating a castle in Camelot, b) Cut the Rope character toy destroying virtual candies, and c) a user transforming regular Ozobot into Captain America character using a smart cover. Adapted from: Soute et al. (2010), www.play.mattel.com, and www.ozobot.com

Create refers when a physical game object creates either unique objects or instantiate new game objects in the environment. A single game object appears in *Furby Connect* Hasbro (2016), so, when a user presses toy body, it creates random game objects on the screen, such as a toy car or a pineapple. The space-themed game from Portico platform presents instantiate game objects when the space ship creates multiple virtual shots on the screen Avrahami et al. (2011). In a building blocks system, users may create new game objects joining its real pieces, such as in Camelot's castle Soute et al. (2010). Create may also include the connected game objects from extended interactions, such as the *DiDi's* Warren (2014) virtual milk from milk box toy, or creating dental foam using a toothbrush toy.

Destroy means when a physical game object destroys other game objects by either extinguishing them or inactivating their game functions. Extinguishing an object may happen in two ways, first as a damaging manner such as hitting a virtual glass-wall using a tennis ball Mueller et al. (2013). Second, as an acquiring manner, as collecting a game object for inventory, such as character toy eating candies in *Cut the Rope* Mattel (2013). In both cases, when a user interacts with toys, other game objects disappear in the environment, like a destroying interaction. An inactivating example happens in Chirpie Fuzzy Flyers (2016) when a player destroys the 'egg' while playing with the plush bird toy. However, he/she destroys its game object's functions instead of destroying the physical object.

Transform indicates when a physical game object transforms another game object in either another one, or transforming its information, such as position, colour, or game state. Therefore, 'transform' covers complementary interactions to both 'creating' and 'destroying' other game objects. *Ozobot* Ozobot & Evollve (2015) a robot toy allow transforming its programmable functions when a user places a playful cover on it. Then, the same robot can turn into either *Hulk* or *Black Widow* character. Taping in Edwin Pi Lab (2015) rubber-duck user can moves game objects on the screen, such as selecting a laundry basket or opening a door.

DATA-group in Figure 30 includes means that a physical game object can send, receive and record data in the interactive environment. In Figure 31, things can *update*, *activate*, or *augment* data from game objects.

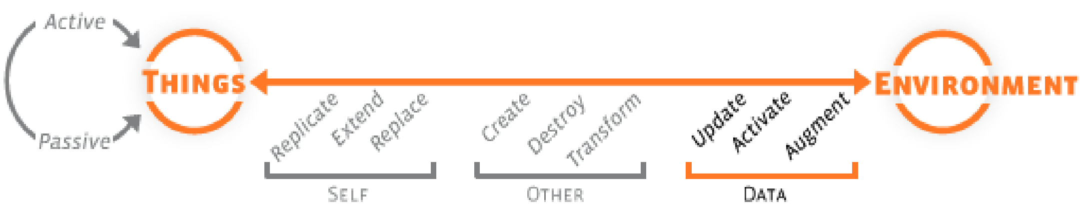

Figure 30 – DATA-group in the things-environment axes.

Figure 31 – How system manages data on physical game objects: a) a user checking Furby game state updates, b) a player activating Pokémon Go Plus accessory, and c) a tablet augmenting character's data using a smart pen. Adapted from: www.hasbro.com, www.pokemongo.com, www.golemarcana.com.

Update refers when a physical game object updates its game state by recording data changings from interacting with any environment element. Data may comprise game state information such as health points (HP), energy points, or equipping game objects. Using a connected application, a user can monitor *Furby Boom* Hasbro (2012) status for feeding, cleaning, and sleeping; then, interacting with the system, the user may update these states in both the toy and application. Updates are either intentional when a user make choices to updating game object's status or are a response of interacting with other game objects and game mechanics. For example, in 'Don't Panic!' a player may update population panic status by combining two *Sifteo Cubes* Mora et al. (2016). Otherwise, the panic state can update after interacting with dynamic game events from the printed cards.

Activate applies when a physical game object activates an action by either sending or receiving data pieces from any environment element. A user can activate a single game action such as when pressing a button, pulling a lever, or shaking a thing. In *Pokémon Go* Niantic (2016) a player can perform game actions such as catching a *Pokémon* or collecting rewards in *'Pokéstops'* by activating a LED button in their wearable devices. Playing Camelot, to release castle pieces, the players must collect three RFID game resources and join them in a table reader activating a smart drawer Soute et al. (2010).

Augment means when a physical game object augments data from any game element providing feedback to users. Feedback can present a visual, auditory or tactile format, such as using LEDs, speakers, and vibrating motors. The system allows users to physical access to game rules and other game states or actions by augmenting the related data. Golem Arcana Harebrained Holdings (2014) application augments both the character figurines and map rules through a connected pen reader. In *Pokémon GO* Niantic (2016) the wearable presents different LED colour to augments several of game actions.

4.1.3 Environment

The environment comprises both the physical and virtual spaces containing the people and things. A physical environment is either indoor or outdoor, and a virtual environment includes both the data inputs and outputs. Concerning the access to information in Figure 32, the environment may be *private* or *shared*. We considered access to the physical interface elements and virtual environment elements such as the game stats, scores, and items.

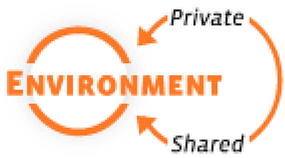

Figure 32 – How happens environment information sharing in the model.

A private environment appears in single player systems and in that where each player has access to his/her toys and to game information pieces. For example, in *Anki Overdrive* Anki (2015) each player has access to a private toy-car and a connected smartphone, so, the players visualise their game stats. A shared environment characterises all sorts of systems where any player has access to the available toys and devices, such as in tabletop games. Moreover, an environment can present both private and shared pieces, so in *Overdrive* system there is a shared smart speed race accessible to both players.

4.1.4 Environment and People

In Figure 33, people may locate in the environment in three ways: single, co-located or remotely located. In the model, the 'single' aspect represents systems without social interaction among people. Co-located people share the same physical environment, and remotely located people share the same virtual environment. Thus, when people are remote located, the system must establish some communication channel among the participants.

Figure 33 – Places in where a person located in the environment-people axes.

4.1.5 People

Hybrid play systems may support social interaction among people. In Figure 34, people can interact through *competition*, *collaboration*, or taking *parallel* actions. When competing, players interact towards the same goals, besides they may collaborate to reach such goals either collaborating in pairs or in groups. Parallel play actions consist of people interacting in multiple means with a system. In Camelot Soute et al. (2010), the people social interact competing and collaborating in groups, while each player takes parallel roles during the gameplay. Some players may recharge resources, and other may build the castle pieces.

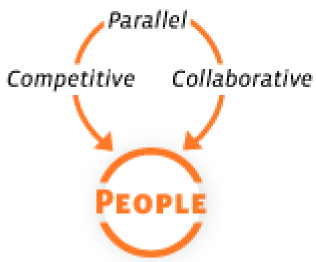

Figure 34 – Means that a person can use social interaction in the model.

4.1.6 People and Things

In Figure 35, hybrid play systems allow people to interact with things in four physical perspectives. First, a user may *visualise* the things, and then *manipulate* those or part of things. People may use other body parts characterising an *embodiment* interaction, such as moving their full-body, or using body information (i.e., heart rate and brain waves). Finally, people interact with their surroundings configuring a *pervasive* interaction, such as walking towards things or interacting with other environmental elements.

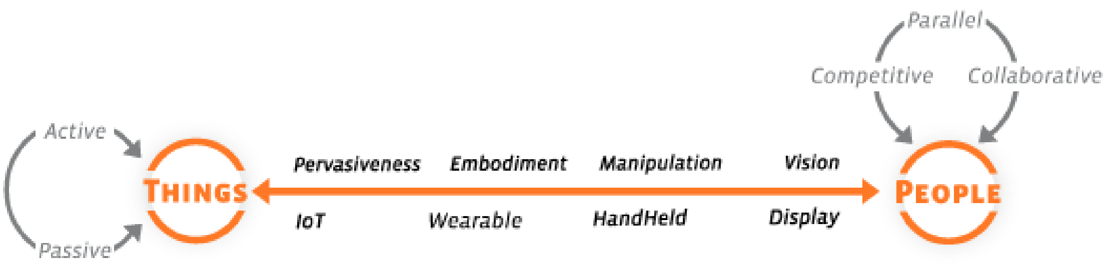

Figure 35 – How people interact with things in a playful system.

A system makes use of I/O technologies to enable the physical interactions. First, there are *displays* including screens, LEDs, or projectors. Then, they may use *handheld devices*, such as smartphones, tablets, and the smart toys itself. Several systems make use of *wearable* technologies, including clothing, accessories, and sensors to measuring either people or the environment information. As a means of transferring data, things can make use of connective technologies or the *Internet of Things (IoT)*, which we can also refer to the Internet of Toys (IoToy).

4.1.7 Physical and Social Domains

Finally, the relationships involving 'things' and the 'environment' happen in a *physical domain*, and 'people' relations occur in a *social domain*. Then combining three axes, in Figure 36 we presented the proposed relational model for hybrid-gameplay interaction. In Table 5 we summarized each term of the model final version.

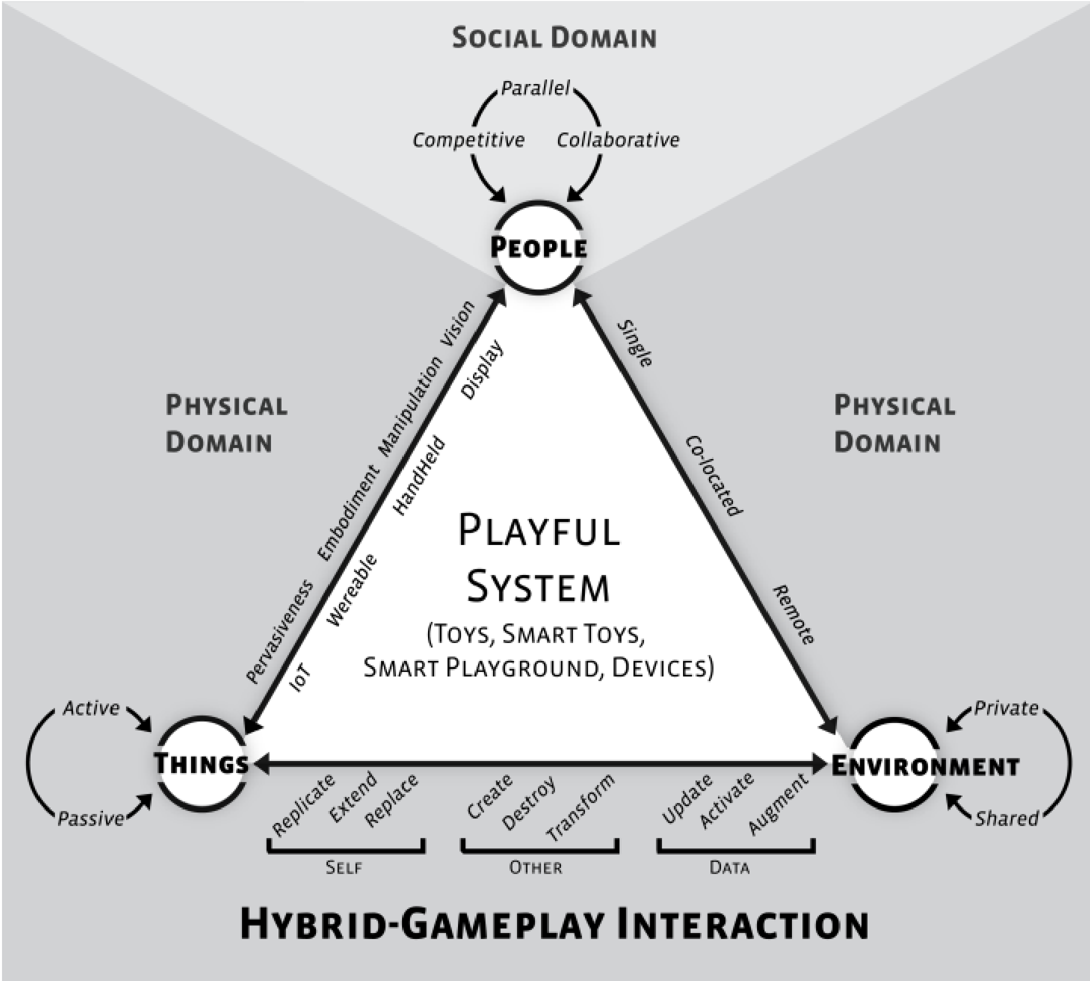

Figure 36 – IoT4Fun, a Relational Model for Hybrid Gameplay Interaction.

Table 5 – A summary of each term's meanings in the model final version.

Things	
Model Term	**Meaning**
Active	Active technologies comprise short and long-range connective protocols, and both embedded and external electronic components attached to things.
Passive	Passive technologies include the use of conductive materials or external cameras, the last, explore AR features and computer vision techniques such as fiducial or QR code markers, and markerless detection (i.e. colour, shape and texture).
Things and Environment	
Model Term	Meaning
SELF	This group includes the different ways that a physical game object can self-represent in the interactive environment.
Replicate	When a physical game object replicates its information and/or physical features in the game environment. Despite the things presenting two formats of self-representation, both physical and replicated game objects are the same.
Extend	When a physical game object extends itself in the game environment while connected to another game object. A game object can extend its

	information and/or physical features. An extended object self-represent two distinct game objects; however, these are both connected and inherent to each other.
Replace	When a physical game object replaces another game object assuming its representation and information in the game environment. A replaced game object is a single self-representation of two connected and inherent game objects.
OTHER	This group comprises the different ways that a physical game object can interact with other game objects in the interactive environment.
Create	When a physical game object creates either unique objects or instantiate new game objects in the environment.
Destroy	When a physical game object destroys other game objects by either extinguishing them (as both damage and acquiring manners) or inactivating their game functions.
Transform	When a physical game object transforms another game object in either another one, or transforming its information (i.e., position, colour, or game state).
DATA	This group includes means that a physical game object can send, receive and record data in the interactive environment.
Update	When a physical game object updates its game state by recording data changings from interacting with any environment element. Updates are either intentional or are a response of interacting with other game elements.
Activate	When a physical game object activates an action by either sending or receiving data pieces from any environment element (i.e., pressing a button, pulling a lever, or shaking a thing).
Augment	When a physical game object augments data from any game element providing feedback to users. Feedback can present a visual, auditory or tactile format, such as using LEDs, speakers, and vibrating motors.
Environment	
Model Term	**Meaning**
Private	The environment is private when each player has individual access to things and/or to system information.
Shared	The shared environment consist when all players have access to things and/or system information.
Environment and People	
Model Term	**Meaning**
Single	A person in a single located system represents a system without social interaction modalities.
Co-located	People co-locate when they share and social interact in the same physical environment.
Remote	People remote locate when they share system information and social interact while physically located in different environments.
People	
Model Term	**Meaning**
Competition	Social interaction modality where people compete towards the same purposes and might perform equal or different actions.
Collaboration	Social interaction modality where people collaborate towards the same goals and might perform equal or complementary actions.
Parallel	Social interaction modality where people play different or independent roles while sharing the same system and environment.
People and Things	
Model Term	**Meaning**
Vision	Physical interaction modality when people have visual access to things.
Manipulation	Physical interaction modality when people manipulate things or part of things.

Embodiment	Physical interaction modality when people use their body parts and movements or essential body information while interacting with things.
Pervasiveness	Physical interaction modality when people interact with things and its surroundings, or inside larger things such as smart playgrounds.
Display	I/O technology that enables visual access through screens, projection or LEDs.
Handheld	I/O technology that supports manipulation tasks such as auxiliary devices like smartphones, tablets, and the smart toys it selves.
Wearable	I/O technology that allows either tracking body information or playful and non-playful devices attached to people's body.
IoT	I/O technology that enables interconnection among things in both long and short range.

4.2 MODELLING PLAYFUL SYSTEMS

The relational model allows describing any hybrid playful system simplifying their interactive aspects in conceptual terms. Extracting data from the review, we selected 20 hybrid play systems to describe them using the proposed model. The goal of this evaluation was to consolidate the model usage in classifying existing systems with multiple setup and characteristics. Following, we presented four of the selected systems, and how we described them using IoT4Fun model. The 16 remaining system's descriptions are available in Appendix C. We described the systems using available data from the both textual and audio-visual sources. Then, we used data from the SLR papers, and from the product's websites, blog and newspapers reviews, including published images and online video content.

4.2.1 Lighthouse

The relational model of Lighthouse Bakker et al. (2008) appears in Figure 37. We started modelling it, by naming the things; first, there are the treasures coins, three sorts of painted circles, and a smart toy lighthouse. Second, we classified the things technologies including their relationships with other game objects. Treasures are the *passive* plastic coins *replacing* the game resources, and the player's main goal is collecting those from the Islands. Lighthouse is an *active* toy allowed to *augment* the game rules providing audio and visual feedback to the players. The smart toy *extends* its light's direction towards the players enabling detecting their movements and position. The lighthouse toy may *activate* game events; such as *creating* a sea monster, also *augmenting* the monster sounds through embedded speakers.

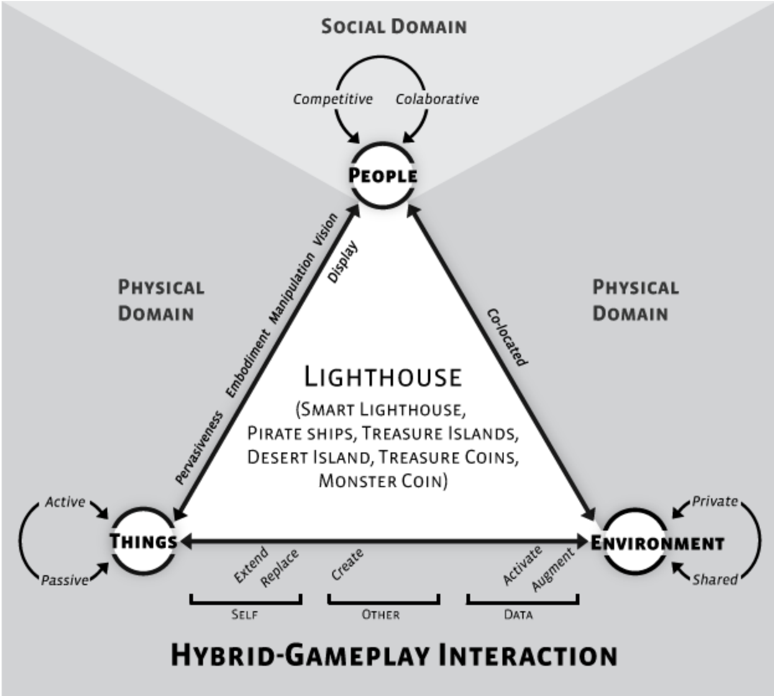

Figure 37 – IoT4Fun relational model for Lighthouse hybrid gameplay interaction.

Continuing, we recognised the information access among things and the environment information. Thus, three sorts of painted circles on the floor *replace* the game scenarios and these are the *private* pirate boats and the *shared* Treasure & Desert Islands. Besides, both smart toy and all treasure coins consist of *shared* resources. Then, we moved to locate the players, and they *co-locate* in such system. Hence, identifying the social relation among people, the game is a *competitive* multiplayer. Also, the players can interact either as individuals or in pairs as a *collaborative* manner.

Later, we described the gameplay as how people physically interact with the things. Lighthouse core gameplay consists of players collecting treasures from Islands and then returning to their boats, therefore players performing both *manipulation* and *embodiment* interactions. In Figure 38, lighthouse toy locates in the Desert Island and it work as a vigilant *displaying* a rotating flashing LEDs allowing the players to *visualise* the *extended* light's direction. When the light catches any player, he/she must return all coins to the Treasure Island. As interaction occurs between the people and its surroundings, such outdoors game consists of a *pervasive* interaction.

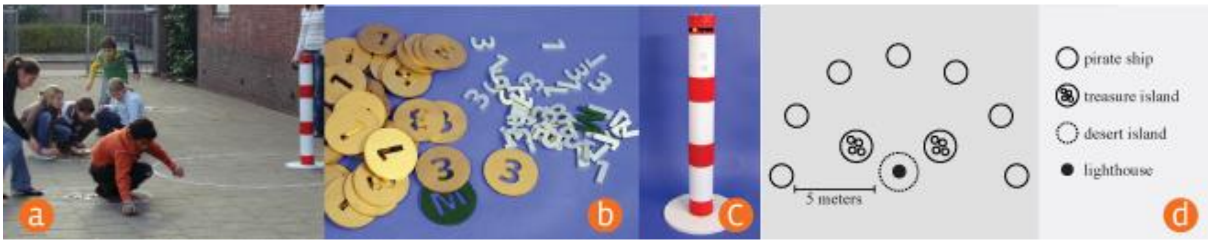

Figure 38 – Lighthouse: a) children collecting treasures during gameplay, b) the real game coins, c) the smart lighthouse, and d) a scheme representing game setup. Adapted from: Bakker et al. (2008)

To complement data, we described other core game mechanics and dynamics, including both victory and failing conditions. Thus, in the Lighthouse when a monster appears, all players must run towards the Desert Island, and the last player to reach it, loses half of her/his treasures. Also, if any player has a monster coin, he/she may befriend with the monster, allowing the player to return to his/her boat, and receive the stolen treasures. After using the monster coin, the player must return it to the Treasure Island. The game is over when players have collected all the available treasures, and the winner is any player or pair who had collected more coins.

In following sub-sections, when presenting systems, we will demonstrate how we combined extracted information into concise descriptions using the model terms. In Section 4.2.2***,*** we will present a serious game from a commercial platform. For Section 4.2.3, we will introduce a smart playground with three different players, and in Section 4.2.4, we will show a storytelling system, presenting the overview of the available interactive contents.

4.2.2 Magikbee (Runaway)

Magikbee Magikbee (2016) is a commercial game platform of *active* wooden building blocks. Each *IoT* block has a single identity allowing the *handheld device* sensors to detect those when the players place them in a *passive* wooden base.

According to the Runaway relational model in Figure 39, the players either can experience a *single* player or *co-located* interaction. Among game levels, some may require help from a *collaborator* to *manipulate* elaborated block sets on the screen. This happens in Figure 40, when a child may receive support from a parent, sibling or friend. Thereby, the environment can be either *private* or *shared*.

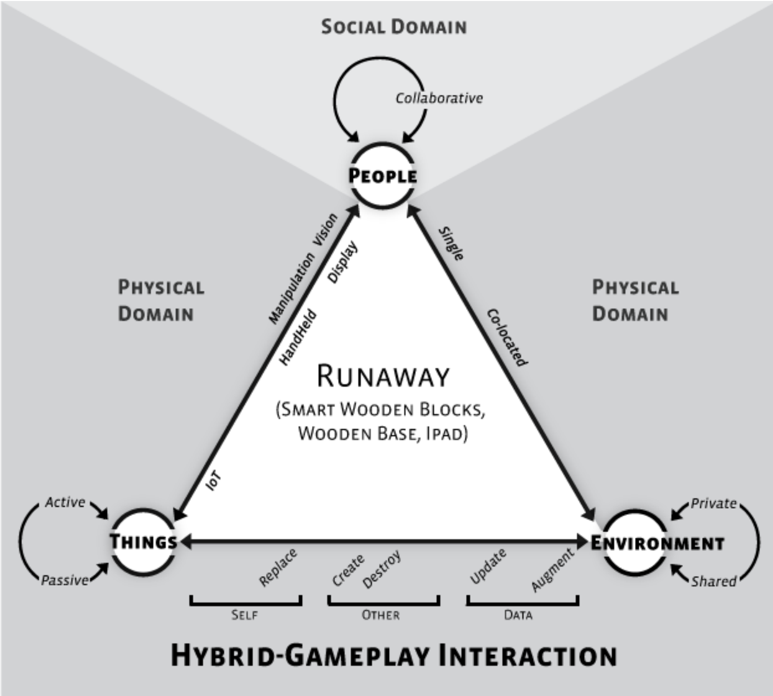

Figure 39 – A relational model for Runaway hybrid gameplay interaction.

Figure 40 – Magikbee: a) a user building a tower in Runaway gameplay, b) other Magikbee available games, and c) a collaborative gameplay experience.
Adapted from: www.magikbee.com.

The core gameplay consists of joining the building blocks to *create* virtual bridges aiding a character that is running away from an enemy. Players can *visualise* on the tablet *display*, the *augmented* instructions to *create* such bridges. The system allows recognising each piece, and when the system identifies a right set, it can *update* game object's information.

In that way, the block set *replaces* the bridge enabling the character preceding its path. However, the stalker character may use the same bridge, and to avoid it the players must *destroy* the bridge by dropping the block set. The game is over either if the enemy catches the main character or if he/she has succeeded all game levels.

4.2.3 Age Invaders

The Age Invaders Cheok (2010) relational model presented in Figure 41 is a pervasive arcade game destined to promote intergenerational play among children, parents, and grandparents. Children and elderly *co-locate* in an *active* tiled LED floor and the parents are *remotely* located in a computer station.

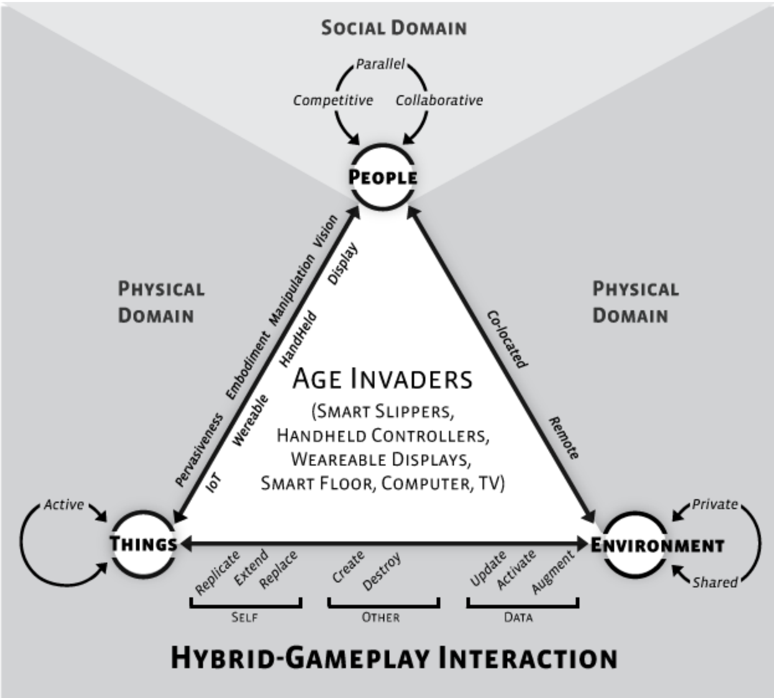

Figure 41 – A relational model for Age Invaders hybrid gameplay interaction.

Each parent *collaborates* with a team, so they *manipulate private* computers to *visualise* the *replicated* virtual floor, enabling access to the current players' position. Also, they may *update* content in the smart floor, such as *replicating* the energy items and *updating* game rules, (i.e. the speed of laser beams and footprints).

In the *shared IoT* floor in Figure 42, the remaining players *compete* through *embodiment wearing active* slippers allowing *replacing* players' position and their identification. The core gameplay consists of the teams *creating* LED shootings towards the opponents to defeat them. Then each player manipulates a *handheld device* to *extend* shooting and *wears* a LED *display augmenting* the energy points.

Children and their grandparents take *parallel* actions since they follow different movement rules *augmented* on the floor. Children must move following the music rhythm and the footprints *displayed* on the floor. Grandparents can move freely through the LED tiles. Both players can collect the energy items; therefore, *destroying* those after stepping on them.

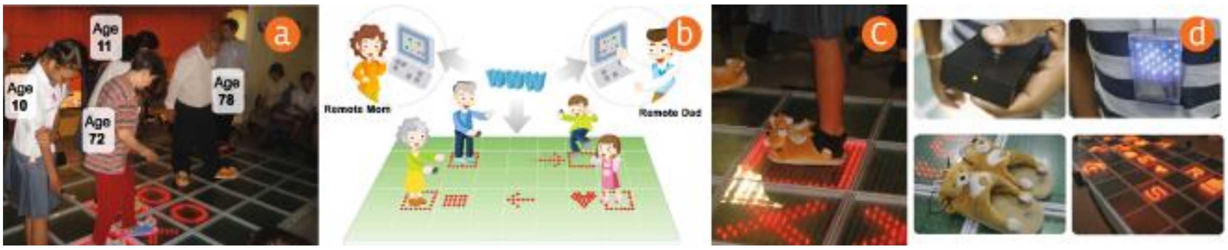

Figure 42 – Age Invaders: a) co-located players on the smart floor, b) a representation of game setup, c) a child wearing a smart slipper, and d) system’s physical game objects. Adapted from: Cheok (2010).

A *display* presents virtual *replicas* of the players and game events to an audience. Every game turn, each player starts with five energy points, and then when suffering attacks, they lose one energy point. Players may score points avoiding the laser beams and collecting the energy items. The game is over after 2 minutes’ play, or when all team members lose their energy points.

4.2.4 Edwin: the Duck

The *Edwin the Duck* Pi Lab (2015) relational model in Figure 43 is a commercial *IoT* storytelling toy system where an *active* rubber duck uses BLE to connect with *handheld devices*, such as tablets and smartphones. Edwin has embedded LED *displays* augmenting its game state information, such as when the toy connects to the application, including it battery status.

Edwin is a *single* player system, so the environment elements are *private*. The connected application presents several play interactions involving both *manipulation* and *visualisation* tasks. The *replicated* Edwin in Figure 44 performs most of the game actions, such as in the storytelling mode, and in other mini games.

Edwin playable story starts by weakening up, brushing its teeth, cooking and then feeding it, doing the laundry, and putting clothes in a closet. Then, to *activate* such game actions, a player may tap in the toy’s body or shake it. Special game events consist of two mini games, popping balloons and the lake racing.

User controls *replicated* Edwin by *manipulating* toy up and down in both games. Also, playing balloons game, the toy *destroys* red virtual balloons when Edwin touches them. Other in-game interactions include *transforming* other objects, such as opening drawers, doors, or moving clothes during the laundry application. Edwin is waterproof, works as Bluetooth speaker to listen to music and as a night-light for children.

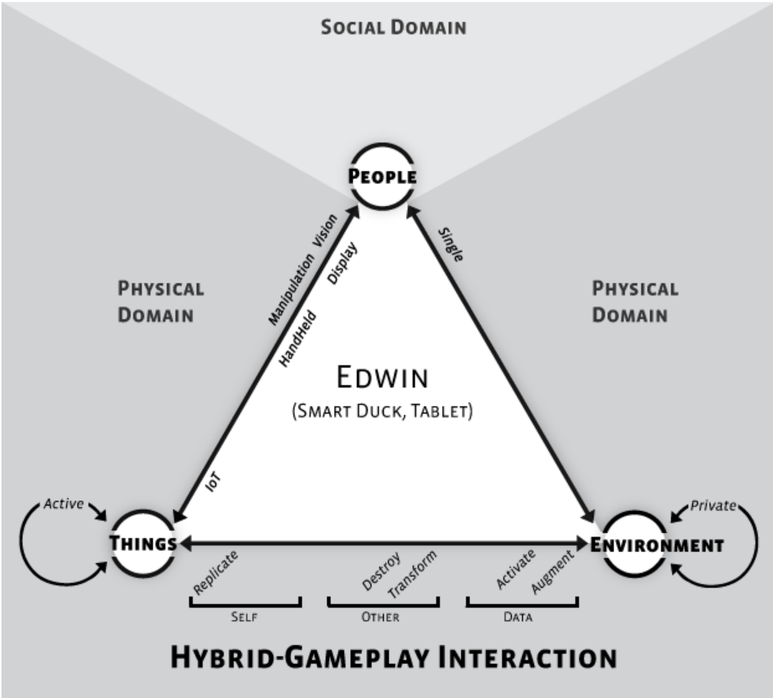

Figure 43 – A relational model for Edwin the Duck hybrid gameplay interaction.

Figure 44 – Edwin the Duck: a) a child playing lake-racing game, b) a tutorial to play popping balloons game, c) a player selecting game objects, and d) Edwin as a night light. Adapted from: www.edwintheduck.com

4.3 SHORT-DURATION WORKSHOPS

We performed changings in first model version to addresses several of student's issues. Modifications motivated us to put in practice a second qualitative user evaluation, also aiming to stress usage of our current proposal. Based on the student's outcomes, we could distinguish the model usefulness along the course schedule. The model presented impact in the initial design stages; these were conception, ideation, design refinement, and documentation. Therefore, we decided to focus our evaluation in these early stages.

We adapted the four first weeks of classes into a short-duration workshop comprising four and eight-hour length. The principal difference between two formats was that the 4-hour happened in a single day and the 8-hour in two consecutive days. In this sense, in the 8-hour, we separated the contents and duplicated the available schedule for each workshop stage. Following in Figure 45, we presented the workshop structure according to the design stages, and then we compare the differences between two formats.

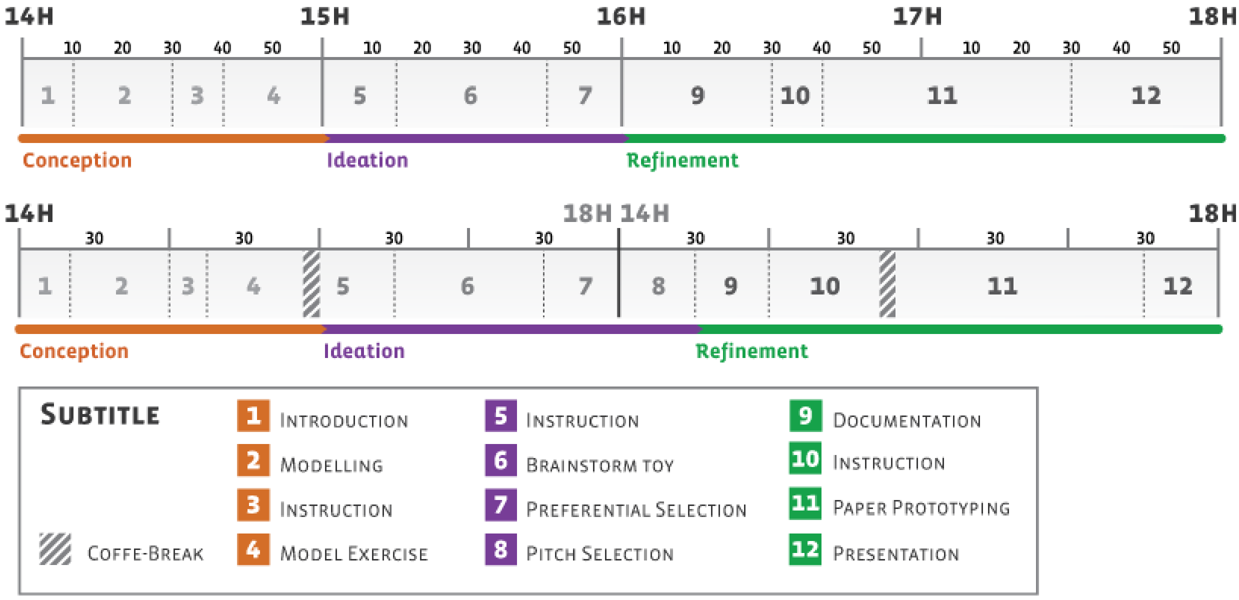

Figure 45 – An infographic comparing 4 and 8-hour workshop schedules.

Conception stage included an introduction to hybrid play design, such as presenting cases from both market and literature. Then, we introduced the model concepts, presenting examples for each term. After an exposure lecture, we performed a similar model's exercise for describing the existing products and prototypes.

In first classes, we asked the students to describe systems, which they had previously searched. For the workshop, we provided the exercise sheets in Figure 46, containing representative images of each system, a bullet point description of the system aspects and gameplay, and a white model to participants select the aspects plus to write down their comments.

Figure 46 – Model exercise sheets and participants using it during workshop.

We distributed six systems that we have rapidly shown during the lecture, including four new cases. Participants experienced the exercise individually, and we assisted them when necessary, such as elucidating the terms meanings.

Ideation stage included the Brainstorm Toy and selection procedure. We used the same instructions from the previous brainstorming session, but we provided to the participants a selected toy set. During classes, we noticed that when the students bring their toys, they often seemed attached to those in sessions. Then, we had to intervene exchanging their toys among the groups.

Another overlooked aspect was that narrative toys, such as franchise figurines and plush toys carry a strong semantic value. Strong character figurines may imply in other related plot elements, and sometimes give biases to ideas. In prototyping cycles, we could refine the game concepts towards more either generic or original narratives.

However, due short time in workshops, we decided to circumvent these issues selecting a set of generic toys avoiding popular brands and narrative aspects. Instead, we selected traditional toys and puzzles such as a ball, a hula-hoop, a shuttlecock, a sword, a Frisbee, a doll, dominos, and building blocks. We also included a few Brazilian traditional toys and games.

Selection stage happened in different ways in the two workshop formats. Four-hour duration workshop consisted of a preferential voting, so each participant elected three favourite ideas. Then we grouped teams based on negotiating their preferences. Eight-hour length, however, included a similar pitch method used in the first classes.

The first day, subjects selected 1-3 ideas to improve using the model and they took the model exercise sheets to their homes. Moreover, we made available a pitch presentation template, containing the virtual model to participants customising. The second day, they presented ideas for the others, and we evaluated each presentation commenting on both strengths and weak points. After a second preferential voting, we aided them in the grouping.

Design refinement stage covered a low-fidelity prototyping activity along with a short documentation using the model. Participants used paper prototyping resources to present their game ideas and testing the core gameplay decisions. In addition to the toys and office materials, we introduced to them a collection of I/O stickers. Paper prototyping for games can focus on several aspects besides the game interface, such as game scenarios and balancing. During classes, we noticed that groups, which had focused on I/O aspects in their first prototypes, had defined the basic game design decisions similar to their working versions.

We created I/O stickers to stimulate the participants in prototyping the interface setup aspects first. Thus, I/O stickers in Figure 47 covers an input, output, and data flow collections. Input collection comprised stickers representing a button, a switch, touch, gesture, position, voice, and image. Output stickers covered a LED, mini-display, speaker, vibrating motor, and a servomotor. Data collections included send, receive and record pictograms.

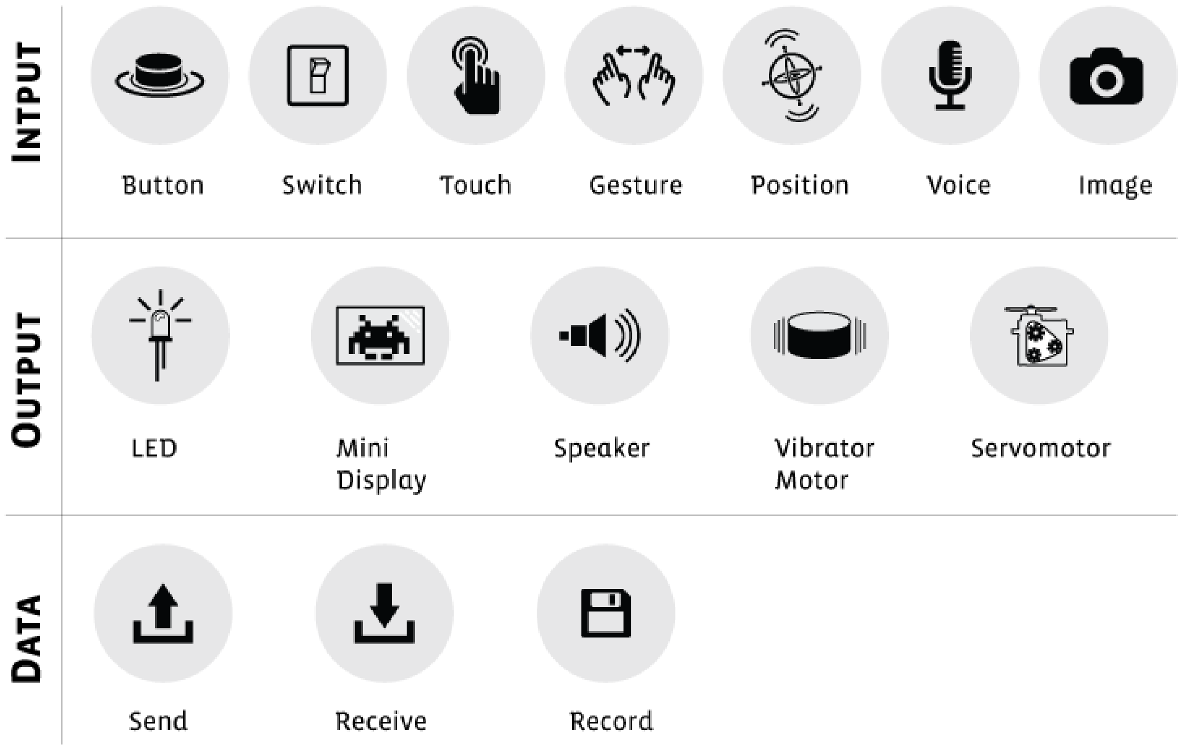

Figure 47 – Graphical representation of I/O stickers.

Short documentation consisted in completing a blank model sheet, after groups discussing and selecting aspects of their concepts. When choosing, they described the gameplay in topics and discriminated the system setup, such as both playful and non-playful things.

In two session formats, we recommended the groups to select the model aspects before prototyping. However, in 8-hour workshop they have done it as an iterative process. We supposed such phenomenon associated with the participants having to experience modelling ideas at home first. In this sense, they engaged in prototyping after a quick group discussion and then returned to complete the model when necessary.

We applied the 4-hour workshops in two contexts, first a pilot test with eight members of the Virtual Reality and Multimedia Research Group (GRVM). Later, we conducted a public workshop in the Design event named *'Ocupe Design'*, which happened at the *Instituto Federal de Educação, Ciência e Tecnologia de Pernambuco* (IFPE) campus. During the public event, we started with 15 participants, but only eight people participated in the prototyping stage.

The 8-hour workshop took place in the private event named *'Recife Summer School'* promoted by the local organisation called *Porto Digital*. Similarly, eight participants experienced the course in two consecutive days. Altogether, the workshop participants included five females and 19 males ageing from 17 to 35 years old. They had either Design or a technological background, and have experience designing games and AR applications.

After excluding the incomplete exercises sheets, subjects produced 8 sheets in the GRVM pilot session, 11 sheets in the IFPE campus, and 12 sheets in 8-hour session. We found no relevant difference in the exercise quality between two formats, and all participants were able to use the model structure and associated the interface elements to their respective concepts.

Observing the replicated system sheets, we noticed that participants had selected the aspects consistently since different participants selected the same aspects when describing the same systems. However, the participant's sheets presented omissions in things-environment and people-things axes. We address such omissions due to limited information on systems, in addition to the particular system variations, such as those presenting two available player modes (i.e., single and co-located).

We compared usage of the first and updated version of the model analysing the selected aspects from similar systems. Participants from workshops presented more consistency in choosing similar aspects on the things-environment axis than the UFPE students had. However, they still presented omissions on the people-things axes, such as when selecting the ‘display’ and ‘vision’ terms.

Ideation session happened similarly in both formats, and the students produced 8-10 ideas each. Due to the selected toy set, participants created nine embodiment interactions ideas, such as using the ball, hula-hoop, shuttlecock, sword, and Frisbee. In this way, the pre-defined set represented an improvement in the Brainstorm Toy sessions.

Regarding the selection approach, in 8-hour format we discussed the strengths and weak points in an oral evaluation with participants, aiding them in selecting refined concepts. However, comparing with the first classes, we found similar issues with one or more group members attached to their first concepts. For example, in the workshop a group had tried to prototype and refine a concept at the same time, in the end, they decided to exchange to a discarded but refined idea.

During classes, *Legends of the World* group had presented a final concept since beginning, which was challenging to refine and improve. Selection method may aggregate a previous concept evaluation to prevent groups in discarding ideas that are suitable for prototyping.

Each workshop session resulted in two refined hybrid game concepts. Also, 8-hour session produced plus six structured ideas during the pitch selection. As results of the workshops, groups produced six paper prototypes and their particular relational models and documentation.

GRVM members produced *AR Detective* and *Tangram 3D,* IFPE participants presented *Painful System* and *Smart LARP*, and 8-hour subjects introduced *Invaders* and *BYG*. Following, we reproduced digital versions of two group’s models, then, we translated their notes on the gameplay information, and described the paper prototypes using their selected model aspects. The remaining models and paper prototype’s descriptions are available in Appendix D.

4.3.1 Smart LARP

Smart LARP in (Figure 48 and Figure 49) is a *pervasive co-located* and *shared* smart playground inspired by live-action role-playing game (LARP) genre. There, at least four players *compete*, while *collaborating* in pairs.

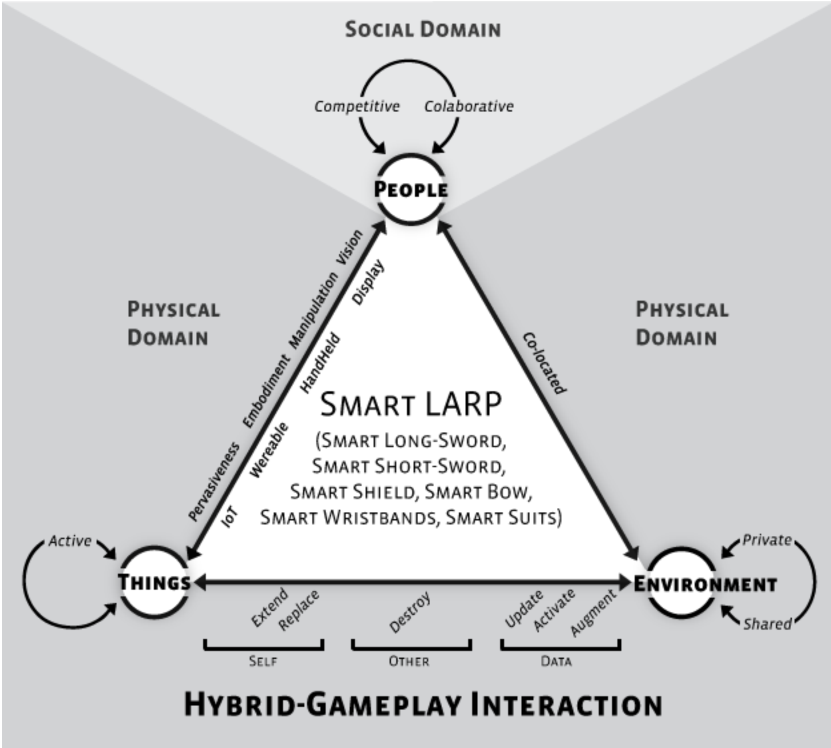

Figure 48 – A relational model for Smart LARP hybrid gameplay interaction.

Figure 49 – Smart LARP paper sheet model, details of paper bracelets and sword, and group using low-fidelity prototype interface elements.

All players *wear* an *active* suit *replacing* a playable character, along with a smart wristband to *augmenting* game rules and actions. Each player *manipulates* a sort of armoury, and those are a long sword for short ranged attack; a short-sword which players use with a shield; and two smart bows and virtual arrows.

All armoury items are *active*, and *IoT* connected, and these may *activate* game actions such as the LED *display* arrow *extended* from the bow. Also, they *augment* actions providing tactile feedback to players, such as the sword vibrating motors.

Gameplay *information* updates real time in the *private* bracelets, while HP and damage data *augments* in the individual suits. When a player trough *embodiment* attacks the opponents using their tools, these will *destroy* HP from *active* suits. In this sense, loses the pair that is defeated, and wins the pair with remaining HP.

4.3.2 Invaders

Invaders in (Figure 50 and Figure 51), is a *co-located* hybrid arcade game where players *compete* in turns. Player 1 may use a set of *passive* building blocks to *create* a tower on an *active* platform.

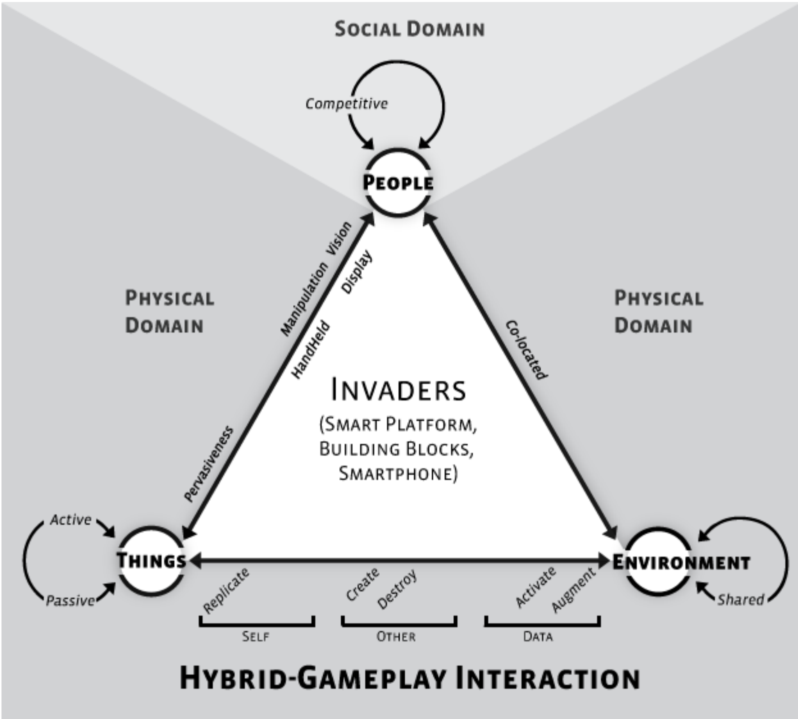

Figure 50 – A relational model for Invaders hybrid gameplay interaction.

Each type of building block has an individual weight, and the platform enables detecting those and keeps the player score. After building in a given time, Player 2 using a *handheld device* may select and *activate* a virtual catastrophe, such as *replicating* a giant monster or a tornado.

Then, using a *passive* AR marker, the smartphone camera detects platform position, *augmenting* the virtual elements on-screen *display*. The platform shakes to simulate *destruction* by dropping the building blocks, so after attack, the remaining blocks will determine a matching score of each player's performance. In this sense, the *creator* player wins if the remaining blocks weight is higher than amount *destroyed* by the second player, and vice-versa.

Figure 51 – Gameplay demonstration of Invaders paper prototype, overall prototype elements and related paper sheet model.

4.3.3 Discussion

Overall, the model update allowed participants in describing their game concepts, and besides the omissions, subjects made use of all axes aspects. They understood several of the model concepts even after experiencing a short learning time. Model update facilitated the participants in selecting the adequate game aspects for their projects.

Moreover, the paper prototyping exercise allowed defining the core gameplay mechanics, and we suppose the I/O stickers simplified such process. Using pre-defined inputs and outputs aided them in selecting among active and passive technologies, as in choosing the technologies on people-things axis. We observed that the data flow collection helped them in selecting the things-environment data-group aspects. For example, the Invaders group had used a button named ‘activate’ in their virtual menu corresponding to the actual ‘activate’ game action. Despite inserting the ‘single’ aspect, the participants used the model to creating alternative game modes including other social play modalities.

Still, we noticed selection mistakes related to the ‘self-representation’ group. Invaders selected ‘replicate’ to representing the virtual catastrophes instead of an appropriated ‘extend’ representation. BYG group presented two self-representations for a single interface element. For them, the individual building blocks would ‘replicate’ while the entire block set would ‘replace’ the game path. In Tangram 3D, the group selected a correct ‘replicate’ aspect to represent the articulated toy, however they associated replica as the ‘other’ game object, so they selected the ‘transform’ term to representing the replicated movements. In this sense, they omitted the ‘destroy’ aspect as result of the collision between virtual replica and other virtual obstacles.

Model usage is an interpretative process; besides aspects presenting pre-defined concepts the designers may appropriate from those, and even re-signified them. An outcome from the second user evaluation was that the model vocabulary portrayed as an adequate tool to introduce hybrid-game design concepts. Model usage allowed no-experienced designers to understand, dominate and create meaningful hybrid game concepts after a short length practice. Furthermore, we believe that the complementary tools assisted us in training designers in overcoming the model aspects.

Following in Section 5, we will summarise this master thesis contributions, discussing general conclusions from the research process, also, pointing topics for a further methodological approach.

5 CONCLUSION

Playful hybrids cover a multitude of genres, comprising from open-ended play scenarios to closed and gameful play modalities. Such playful systems provide experiences located either indoors or outdoors, promoting since visual and manipulation tasks to full-body and pervasive interactions. Playful interface design involves both active and passive technologies, varying from computer vision and AR resources to embedded & interconnected technologies, embracing microcontrollers, small sensors, and actuators.

Despite novelty and potential of hybrid play interactions, many are issues related to user engagement in either short or long term. Researchers aimed to address these problems by providing theoretical and practical tools. However, a few studies had integrated such approaches. Meantime, the market has created engagement mechanisms such as developing either playful platforms or narrative products. Furthermore, they had invested in associating play content with popular brands, making those customizable and updatable, including the use of artificial intelligence resources.

Our work aimed to demonstrate that when selecting aspects from the first hybrid concepts might prevent investing in flaw play experiences to users. In conclusion, the hybrid gameplay approach may intervene in related user engagement issues by refining game concepts towards a meaningful interactive experience. Creators may achieve it by aggregating both semantic and interaction values of game objects to playful interface design practices. Following, we summarised the study contributions, including generated theoretical-practical tools, data categorization, developed prototypes & concepts, and the published academic research.

5.1 CONTRIBUTIONS

This master thesis was fruitful in achieving both general and specific research goals. Our primary research aim was assisting the community with enhanced design practices for the hybrid gaming and toy computing fields.

First, we (1) categorised the available related HCI knowledge on the hybrid play field by performing a systematic literature review covering work published within 2008 to 2016. Additionally, we conducted a market review, extending our contribution with an industry perspective. We decided to categorise the playful systems relating its thematic and play purpose, so these vary from enhancing traditional play experiences to gameful design, including serious approaches for education and physical & social therapy, and tangible interactive storytelling. Literature presented relevant research on all topics among the covered years, and the industries have introduced several related products on the market.

Hybrid play systems are complex design artefacts, and we (2) proposed the relational model capable of describing different scenarios of smart play by considering the interface elements as physical game objects. Such approach enabled us in describing the mapped system setups, relating three core entities, the *things*, the *environment*, and *people*. In this sense, things are both playful and non-playful artefacts enabling interaction between people and the environment. Things can self-represent within the system and interact with other game elements; also allow receiving, sending and recording data. Playful things as game objects promote both physical and social experiences mixing traditional and digital play with integrated technology.

Proposed model allows visual access to complexity level considering several of their interactive aspects. Observing the number of the physical interface elements is not a single point of view for determining the complexity in such systems. Design complexity for hybrid play systems combines the amount of things and connected devices, with other technological, social, physical, and interactive aspects. For example, a tabletop game can present multiple tokens, and those may provide the same interaction modalities. In this sense, a smart playground with fewer playful things may explore technological resources collecting both physiological and environmental data. Then, a system dealing with such private and shared information may present complex matters during the development.

In addition to the model synthesis in classifying the existing systems, we (3) evaluated our theoretical contribution as a conceptual tool for designing new hybrid play products. Such approach allowed us in assisting both developers and designers in creating meaningful hybrid gameplay concepts and prototypes.

We evaluated the model βversion in a project-based class with Design, Computer Science, and Engineering students from both undergraduate and graduate levels. Classes resulted in six working prototypes that end-users could experience in 106 tests during public sessions. The student’s outcomes in the playtesting sessions presented both qualitative and quantitative data on player’s fun and short-engagement experience. We believe that the design improvements suggested by users in the playtests might lead benefits to long-term engagement matters of the prototypes.

Moreover, we interviewed the students to access the impact of the model usage during the creative, design and development stages. Interview's outcomes enabled us to access the model usefulness and recognised points in the model that required adjustments. Therefore, we performed improvements based on the student's feedback, and we evaluated those in a sequence of creative workshops. Short-duration practices had stressed our proposal, enabling the participants to understand available design spaces and creating six new hybrid game concepts.

In summary, proposed model worked as both a *classifying tool* and a *creative tool*, and in either context, its usage is part of an interpretative process. Designers may appropriate from the pre-defined aspects applying those in their contexts. As a classifying tool, the model presented efficiently to describe the overall system setup, and the model vocabulary facilitated in describing the interface-gameplay interaction. Joining the existing systems with those from the assessment stage, in this master thesis we classified 33 hybrid playful systems using the model.

As a creative tool, the model usage has presented its potential in the initial design stages named conception, ideation, and design refinement, including low-fidelity prototyping and documentation. These first steps grounded further decisions during the advanced prototyping cycles. IoT4Fun enabled the groups to create 12 original hybrid games, including six functional prototypes. Also, the model assisted in understanding design complexity of their concepts, and to either improve or select the essential aspects. Vocabulary had assisted the teams in internal and external communication by simplifying the concepts and in short but meaningful terms.

Major parts of this master thesis are available as academic research contributions in two full conference papers. First, we released the model βversion including part of literature review, and later, we issued the model 16-week assessment, along with the working prototypes, and the model improvements. So far, we published these related results in two international conferences on HCI:

- de Albuquerque A.P., Breyer F.B., Kelner J. (2016) A Relational Model for Playful and Smart Game Design. In: Marcus A. (eds) Design, User Experience, and Usability: Novel User Experiences (DUXU 2016) held as part of the 18th International Conference on Human-computer Interaction (HCII 2016). Lecture Notes in Computer Science, vol 9747. Springer, Cham. DOI: 10.1007/978-3-319-40355-7_24

- de Albuquerque A.P., Breyer F.B., Kelner J. (2017) Modelling Playful User Interfaces for Hybrid Games. In: Streitz, Norbert, Markopoulos, Panos (eds) Distributed, Ambient and Pervasive Interactions (DAPI 2016) held as part of the 19th International Conference on Human-computer Interaction (HCII 2017). Lecture Notes in Computer Science, vol 10291. Springer International Publishing. DOI: 10.1007/978-3-319-58697-7_48

5.2 FUTURE WORK

This master thesis had focused on the engagement issues aiming to aid creators in designing meaningful hybrid play solutions. However, there are several challenges related to functional prototyping, user testing, as in assuring security, fabricating and distributing these playful systems. In this way, researchers and practitioners find a broader range of subjects for intervention.

As a future work, we intend to continue creating and improving the theoretical-practical tools to intervening in several design stages. Along with the conceptual model and its descriptive exercises, we proposed the complementary tools that aided creators in ideation and low-fidelity prototyping stages.

The Brainstorm Toy tool was effective while assisting the participants in creating over 60 original ideas during creative sessions. The proposed discussion list enabled subjects extracting from the toys its materials along with their computational, semantic and interactive features. Including the toy set comprising different sorts of related physical exertion assisted the groups in generating embodied, embedded and tangible interactions.

However, still space for improvements on the idea selection stage. The pitch models selection presented as a strong approach for the idea refinement. Although the preferential voting was sufficient to selecting the ideas, it was not adequate to categorise the concepts potential and their complexity. We supposed as a future topic, the ideation method might include a formal evaluation of the design complexity, using the proposed model. Therefore, a structured selection technique may guide creators in selecting potential concepts that are suitable for prototyping.

The I/O stickers worked as an efficient tool for paper prototyping the hybrid games, making it a more focused and agile process. Comparing the paper prototype outcomes from the first classes to those from the workshops, participants completed this task in a shorter time. The proposed sticker collections facilitated them in presenting the game ideas, and to both represent and select the I/O aspects.

Nonetheless, we understand that workshop participants did not experience in developing the working versions to their concepts. Therefore, many of the selected I/O aspects are sensitive to changings in consequence of the prototyping cycles. A critical issue in such systems consists in integrating the technologies with the proposed contents, and in making these robust enough to perform playtesting sessions. A subsequent step of transforming prototypes into largely scaled products involves another group of challenges, such as physical and cyber security matters.

We believe that the complementary tools assisted us in training designers in overcoming the model aspects, and in consequence, we might outline a further methodological approach for designing hybrid playful systems, projecting the toys as physical game objects. Therefore, the method must include tools to assist in advanced prototyping stages, including how to turning prototypes into robust, engaging, and safe products. When continuing exploring such approach, we supposed that our research contributions would aid researchers and professionals in creating new and meaningful hybrid gameplay experiences.

Moreover, as additional improvements to our work, we aim to promote a further quantitative evaluation of the model, performing a comparative experiment using a control group. Besides, we believe that model structure might include an expanded version, where designers may discriminate the things and the other game objects in the thing-environment axis. In that way, the creators can plan specific behaviours for the selected hybrid-gameplay interaction aspects. Another enhancement may consist in distinguishing the real from virtual game objects in the model.

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APPENDIX A – SLR RESULTS

In the present Appendix, we showed two tables mentioned in Section 2; first, Table 6 compiled playful system prototypes present in 93-selected articles and DOI links of its particular references. In Table 7, we presented a list of 120 commercial products, including year launch, copyright information, and external links.

Table 6 – A full-list of 93 selected articles from SLR

Playful System	Authors	DOI
Totti	Heijboer et al. (2008)	10.1145/1463160.1463178
Tangicons	Scharf et al. (2008)	10.1145/1463689.1463762
Topobo	Parkes et al. (2008)	10.1145/1357054.1357232
Pousey	Philetus et al. (2008)	10.1145/1347390.1347402
Brag Fish	Xu et al. (2008)	10.1145/1501750.1501816
Lighthouse	Bakker et al. (2008)	10.1145/1463160.1463165
Stop the Bomb and Timeball	Hendrix et al. (2008)	10.6100/IR754836
Picture This!	Vaucelle & Ishii (2008)	10.1145/1409635.1409683
wIzQubes	Zhou et al. (2008)	10.1016/j.procs.2013.11.015
Toewie	Abeele et al. (2008)	10.1007/978-3-540-88322-7_12
Coloured Hammer, Coloured Block, Rotating Coloured Block	Li et al. (2008)	10.1007/978-3-540-88322-7_18
W41K	Hinske et al. (2009)	10.1145/1517664.1517691
Kurio	Wakkary et al. (2009)	10.1145/1517664.1517712
Linguabytes Platform	Hengeveld et al. (2009)	10.1145/1517664.1517702
Boston Museum of Science	Horn et al. (2009)	10.1145/1518701.1518851
LEGO Bionics	Nielsen et al. (2009)	10.1145/1551788.1551800
Art of Defense	Huynh et al. (2009)	10.1145/1581073.1581095
Sharetable	Yarosh et al. (2009)	10.1145/1551788.1551806
Sensory Bicycle and Gateball	Lee et al. (2009)	200906/20090617
AR Paddles	Hornercker & Dünser (2009)	10.1109/ICVR.2009.5174203
PlayCubes	Jacoby et al. (2009)	10.1016/j.intcom.2008.10.007
Keepon	Kozima et al. (2009)	10.1007/s12369-008-0009-8
Augmented Doll House	Freed et al. (2010)	10.1145/1810543.1810552
Video Playdate	Yarosh et al. (2010)	10.1145/1753326.1753514
Augmented Kinight Castle	Farr et al. (2010)	10.1145/1810543.1810548
Paper-based Storytelling	Garzotto & Bordogna (2010)	10.1145/1810543.1810553
Make a Riddle	Hunter et al. (2010)	10.1145/1810543.1810572

TellTable	Cao et al. (2010)	10.1145/1718918.1718967
PuzzleTale	Shen et al. (2010)	10.1145/1899687.1899693
FPS-VR and FPS-AR	Tedjokusumo et al. (2010)	10.1109/TSMCA.2009.2028432
Camelot, Save the Safe and Heart Beat	Soute et al. (2010)	10.1007/s00779-009-0265-0
Age Invaders	Cheok (2010)	10.1007/978-1-84996-137-0_6
Feedball, LEDtube, ColorFlare, MultimodalMixers and Swinxbee	Bekker et al. (2010)	10.1007/s00779-009-0264-1
Turn-Taking Games	Brok & Barakova (2010)	10.1007/978-3-642-15399-0_11
Biofeedback Samurai	Munekata et al. (2010)	10.1007/978-3-642-15399-0_41
Face Cube Museum	Bang et al. (2010)	10.1007/978-3-642-15399-0_43
ViPleo	Gomes et al. (2011)	10.1145/2071423.2071427
Portico Platform	Avrahami et al. (2011)	10.1145/2047196.2047241
Futura	Speelpenning et al. (2011)	10.1007/978-3-642-23771-3_45
Motionbeam	Willis et al. (2011)	10.1145/1978942.1979096
Rope Revolution Platform	Yao et al. (2011)	10.1145/2071423.2071437
T-Games	Mendes & Romão (2011)	10.1145/2071423.2071438
BobIt! Snake	Slyper et al. (2011)	10.1145/1935701.1935744
Catching Dishes, Collecting Eggs, Preparing Recipes and Flying Dragons	Geurts et al. (2011)	10.1145/1935701.1935725
Towards Utopia	Antle et al. (2011)	10.1145/1999030.1999032
TacTower Platform	Fogtmann (2011)	10.1145/2000756.2000768
Free-play Robot Interaction	Cooney et al. (2011)	10.1109/Humanoids.2011.6100847
Pinoky	Sugiura et al. (2012)	10.1145/2207676.2207780
NKVision Farm Game	Marco et al. (2012)	10.1504/IJART.2012.046272
AR Zoo Game	Tsong et al. (2012)	10.1016/j.sbspro.2012.11.045
Marbowl	Faber & Hoven (2012)	10.1007/s00779-011-0405-1
TagTile platform	van Delden et al. (2012)	10.1007/978-3-642-33542-6_19
Ninja Track	Katsumoto et al. (2013)	10.1145/2460625.2460628
TabletopCars Platform	Dang & André (2013)	10.1145/2460625.2460630
Digital DreamLab	Oh et al. (2013)	10.1145/2460625.2460633
HideOut	Willis et al. (2013)	10.1145/2460625.2460682
Augmented Jigsaw Puzzle	Antle et al. (2013)	10.1145/2460625.2460635
RaPIDO Platform	Soute et al. (2013)	10.1145/2485760.2485779
Beelight	Shen et al. (2013)	10.1145/2485760.2485813
BodyBug	Segura et al. (2013)	10.1145/2470654.2466461
RoboGames	Martinoia et al. (2013)	10.1016/j.robot.2013.04.017
AR Water Cycle Mini-game	Furió et al. (2013)	10.1016/j.compedu.2012.12.015

AR GO, EmoPoker, AR Drums, AR Calligraphy Trainer	Yamabe et al. (2013)	10.1007/s11042-011-0979-7
Augmented Home	Offermans & Hu (2013)	10.1007/978-3-642-41106-9_4
Football Training Playground	Jensen et al. (2013)	10.1007/978-3-642-41106-9_6
Fat and Furious	Pillias et al. (2014)	10.1145/2556288.2556991
Fish Game and Penguin Game	Geurts et al. (2014)	10.1145/2658537.2658706
CountMeIn	Wolbert et al. (2014)	10.1145/2663806.2663835
Back to the Future (Food Chain Game)	Gnoli et al. (2014)	10.1145/2540930.2540972
Remote Impact	Mueller et al. (2014)	10.1145/2540930.2540937
Augmented Skateboard	Pijnappel & Mueller (2014)	10.1145/2540930.2540950
3D-Paint LEGO Installation	Halskov et al. (2014)	10.1145/2663806.2663831
Maze Commander	Sajjadi et al. (2014)	10.1145/2658537.2658690
SmartPads	Hafidh et al. (2014)	10.1007/s11042-013-1459-z
PhysiCube	Vandermaesen et al. (2014)	10.1145/2540930.2540936
StoryCube	Wang et al. (2014)	10.1007/s11227-012-0855-x
Wonderland Story CAVE	Nakevska et al. (2014)	10.1007/978-3-662-45212-7_7
Wheelchair Revolution	Gerling et al. (2015)	10.1145/2724729
Sticky Actuator	Niiyama et al. (2015)	10.1145/2677199.2680600
HandiMate	Seehra et al. (2015)	10.1145/2677199.2680570
FingAR Puppets	Bai et al. (2015)	10.1145/2702123.2702250
Social Robot AR Dramatic Play	Han et al. (2015)	10.1007/s11423-015-9374-9
TangiSense	Kubicki et al. (2015)	10.1007/s00779-015-0891-7
Augmented TGC Yugi-oh!	Sakamoto et al. (2015)	10.1007/s11042-015-2751-x
Kinjiro	Nakadai et al. (2015)	10.1007/978-3-319-24589-8_19
Earth Shake	Yanner et al. (2016)	10.1145/2934668
OptiTrack Tower Defence	Todi et al. (2016)	10.1145/2851581.2892448
Augmented Ping Pong	Mueller et al. (2016)	10.1145/2858036.2858277
Gauss Sense	Liang et al. (2016)	10.1145/2851581.2889434
Balance Ninja	Byrne et al. (2016)	10.1145/2967934.2968080
SynFlo	Okerlund et al. (2016)	10.1145/2839462.2839488
Programming Power Blocks	Wang et al. (2016)	10.1145/2839462.2839491
BSsmart, ThinkM, Adaja and ProDraw	Spiel et al. (2016)	10.1145/2839462.2839495
Patcher Alfombra Apliqué	Bergmask & Fernaeus (2016)	10.1145/2839462.2839473
Tobe	Gervais et al. (2016)	10.1145/2839462.2839486
MagicBuns	Huysduynen et al. (2016)	10.1145/2839462.2839492
ChillFish	Sonne & Jensen (2016)	10.1145/2839462.2839480

TactileVR Game	Shapira et al. (2016)	10.1109/ISMAR.2016.25
Don't Panic!	Mora et al. (2016)	10.3233/AIS-160396
The Farm Game	Zidianakis (2016)	10.1007/978-3-319-55834-9_3
TurnTalk	Melonio et al.(2016)	10.1007/978-3-319-52836-6_28

Table 7 – A full-list of commercial systems.

Playful Commercial System	Copyright	Website
Fuzzy Flyers	Fuzzy Flyers (2016)	fuzzyflyers.com
Ubooly	Smart Toy LLC (2012)	ubooly.com
Miraffe	Miraffe Kids/Kickstarter (2016)	Miraffe-Kickstarter
R/C Toy Car	Joybien (2012)	joybien.com
Toymail	Toymail (2016)	toymail.co
Amiibo	Nintendo (2014)	nintendo.com/amiibo
BB8 Sphero Special Edition (+ Force Band)	Sphero (2015) and (2016)	sphero.com/
playDXTR	DXTR Labs (2015)	playdxtr.com
Robo Wunderkind	Robo Wunderkind (2015)	robowunderkind.com/
Leka	Leka/Indiegogo (2016)	leka-Indegogo
Ozobot	Ozobot & Evollve (2015)	ozobot.com
Playmation Marvel Avengers	Hasbro & Disney & Marvel (2015)	playmation.com
Avakai	Vaikai (2016)	vaikai.com
Edwin	Pi Lab (2015)	edwintheduck.com
Fabulous Beasts	Sensible Object/ Kickstarter (2016)	fabulous-beasts-Kickstarter
Badanamu	Calm Island Co. (2015)	badanamu.com
Marbo Basall	Basall (2015)	marbobasall.com.br
Codie	CodieLabs (2016)	getcodie.com
IQube	Llana/Indiegogo (2016)	iqube-Indiegogo
Dynepod	Dynepic (2015)	dynepic.com
Povi	The Povi Team/Kickstarter (2016)	povi-Kickstarter
Cayla	Vivid Toy Group (2014)	myfriendcayla.co.uk
Dash & Dot	Wonder Workshop (2015)	makewonder.com
Cannybots	Cannybots/Kickstarter (2015)	cannybots-Kickstarter
Hackaball	Many Map/Kicstarter (2016)	hackaball.com
Oliba	Smarty Crew/Indiegogo (2016)	oliba.fr
Hello Barbie	Mattel (2016)	mattel.com
Pocket Racing	PTah Tech (2016)	pocket-racing-KickMasters

Cubbeto	Primo Toys (2013)	primotoys.com
Smart Toy	Hasbro/Fisher and Price (2016)	smarttoy.com
Attocube	Attocube/Indiegogo (2015)	attocube-Indiegogo
Moff Band	Moff (2015)	moff.mobi
Osmo	Tangible Play (2014)	playosmo.com
Anki Overdrive	Anki (2015)	anki.com
Magikbee	Magikbee (2016)	magikbee.com/
Smart Letters and Numbers	Marbotic (2016)	marbotic.fr/smart-letters/
Sensibots	Dynepic (2014)	sensibots-Dynepic
Smart Toybox	Smart Toybox (2016)	smarttoybox.com/
Cognitoys	Cognitoys/Kickstarter (2015)	cognitoys.com/
Mozbii ColorXPlore	Mozbii (2014)	mozbii.com/
Furby Boom e Conect	Hasbro (2014) and (2016)	hasbro.com
Trobo	Trobo/Kickstarter (2014)	mytrobo.com/
ROXs	A-Champs/Indiegogo (2016)	roxs-Indiegogo
Plane Quest	Tabletop Interactive/Kickstarter (2013)	planequest-Kickstarter
Zombies, Run!	Six to Start/Kickstarter (2016)	Sixtostart-Kickstarter
PinBox 360	Cardboard Teck Instantute/Kickstarter (2016)	pinbox-Kickstarter
Apptivity Mattel	Mattel (2013)	mattel-apptivity
Tiggly	Tiggly (2014)	tiggly.com/
Mover Kit	Mover Kit/Kickstarter (2016)	mover-kit-Kickstarter
ePaw Arena	ePawn (2016)	epawn.fr/
Dice +	Game Technologies (2014)	grandst.com
Zombies Burbz	AppGear (2012)	zombieburbz-Itunes
DreamPlay Toys	JAKKS Pacific (2016)	jakks.com/
DiDi	Warren/Kickstarter (2014)	didi-Kickstarter
Monster Matic	Mico Studio (2014)	monstermaticapp.com/
Mattel ThingMaker	Mattel (2016)	thingmaker.com/
SpellShot	Hasbro (2012)	spellshot.net/
LEGO Fusion	LEGO (2014)	lego.com
HoloGrid	Tippit Studio (2016)	hologrid-Kickstarter
Golem Arcana	Harebrained Holdings LLC (2014)	golemarcana.com/
Pokemon Go Plus	Niantic & The Pokemon Company (2016)	pokemongo.com
World of Yo-ho	IELLO/Volumique/Kickstarter (2014)	yoho.io
Makie Fablab	MakieWorld (2014)	mymakie.com
LEGO Dimensions	LEGO (2015)	lego.com

Disney Infinity	Disney (2013)	Disney-Infinity
Skylanders	Activision (2013)	skylanders.com
Disney AppMates	Disney Pixar (2012)	appmatestoys.com
Cocolo Bear	CUBE (2012)	cocolo-bear-Japan
Pictuterium Digital Fish Tank	Takara Tomy Arts (2015)	picturerium-Japan
Anpanman Kids Brain Training Mat	Anpanman (2015)	anpanman-Japan
Pokemon Get	Takara Tomy Arts (2015)	pokemon-get-Japan
Taiko no Tatsujin	Netolabo (2013)	controller-drum-Japan
Anpanman Let's Go Driving	Anpanman (2014)	anpanman-Japan
Nanoblock Motion	Schylling Inc (2015)	nanoblockus.com/
Colour Cacth Pen	JouJou (2015)	color-catch-pen-Japan
Joujou Cube Touch	JouJou (2015)	joujou-cube-Japan
HatchMail	Spin Master (2016)	hatchimals.com
Fue-kon	Takara Tomy (2016)	fuekon-Japan
Smapon Communication Toy	Takara Tomy (2016)	smapon-Japan
Star Wars Interactive Globe	Amanda Imp (2016)	star-wars-Japan
Mario Kart Wii Remote	RC Toy (2016)	mario-kart-wii-Japan
Denchu Troope	Mega House (2016)	denchu-troope-Japan
Dragon Hunting	Takara Tomy (2015)	dragon-hunting-Japan
Tsuku Raji RC Toy	RC Toy (2015)	tsuku-raji-Japan
Monster Shooting	Takara Tomy (2016)	monster-shooting-Japan
Gokiraji	RC Toy (2016)	gokiraji-Japan
Oniri Islands	Tourmaline Studio/Volumique/Kickstarter (2017)	oniri-islands-Kickstarter
Bloxels	Pixel Press/Kickstarter (2016)	bloxels-Kickstarter
SuperSuit	SuperSuit Inc/Indiegogo (2017)	supersuit-Indiegogo
Swapbots	SwapBots/Indiegogo (2017)	swapbots-Indiegogo
Strike	Wu Pan/Indiegogo (2017)	strike-Indiegogo
PlayBrush	PlayBrush (2016)	playbrush.com
Romo	Romotive/Kickstarter (2012)	romo-Kickstarter
Yum&Done	Slow Control (2016)	slowcontrol.com/
Chip	WoWee (2016)	wowwee.com/chip
Lumi	WoWee (2016)	wowwee.com/lumi
I-Loom	Style Me UP! (2016)	i-loom.stylemeup.com
Gameband Minecraft	Feargal Mac/Indiegogo(2014)	Gameband-Indiegogo
Linkitz	Linkitz (2016)	linkitz.com
Skechers Kids Game	Skeechers (2015)	Skechers-Kids
Think& Learn Toys	Hasbro/Fisher&Price (2016)	fisher-price.com

Herokins	Coming Soon Tech (2017)	herokins-Indeogogo
LeapFrog	Leap Frog Entrerprises (2014)	leapfrog.com
Orboot	Play Shifu (2017)	orboot-Kickstarter
JewelBots	JewelBots (2015)	jewelbots-Kickstarter
Airblock	Makeblock (2017)	airblock-Kickstarter
Puzzlets	Digital Dream Labs (2016)	digitaldreamlabs.com
Code&Go Mouse	Code & Go (2016)	robot+mouse
Apptivity Fisher Price Toys	Mattel/Fisher & Price (2014)	fisher-price.mattel.com
BRUSHIES	Sasa Sallamon (2017)	brushies-Indiegogo
FollowGrams	Flycatcher Inc. (2017)	followgrams-Indiegogo
Ziro	Raja Jasti (2016)	ziro-Indiegogo
Tinkerbots	Kinematics GmbH (2016)	tinkerbots-Indiegogo
AppKids	Dinesh Lalvani (2016)	appykids-Indiegogo
Photon	Mike Grzes (2016)	photon-Indiegogo
Grumblies	Kicstarter (2015)	grumblies-Kicstarter
Lego Mindstorms	LEGO (2012) and (2017)	lego.com
PlayTable	PlayTable (2016)	playtable.com/
Lego Nexo Knights	LEGO (2015)	lego.com

APPENDIX B – 16 WEEKS COURSE RESULTS

In the present Appendix, we showed four remaining descriptions & models of student's prototypes, mentioned in Section 3. First, BUD Monster (see Figure 52 and Figure 53) is a hybrid Kinect game inspired by Japanese monster movies or 'kaiju' genre. In a *private* environment, a player *replaces* a giant marine monster in the game world and the player interacts by an *embodiment* using Kinect technology.

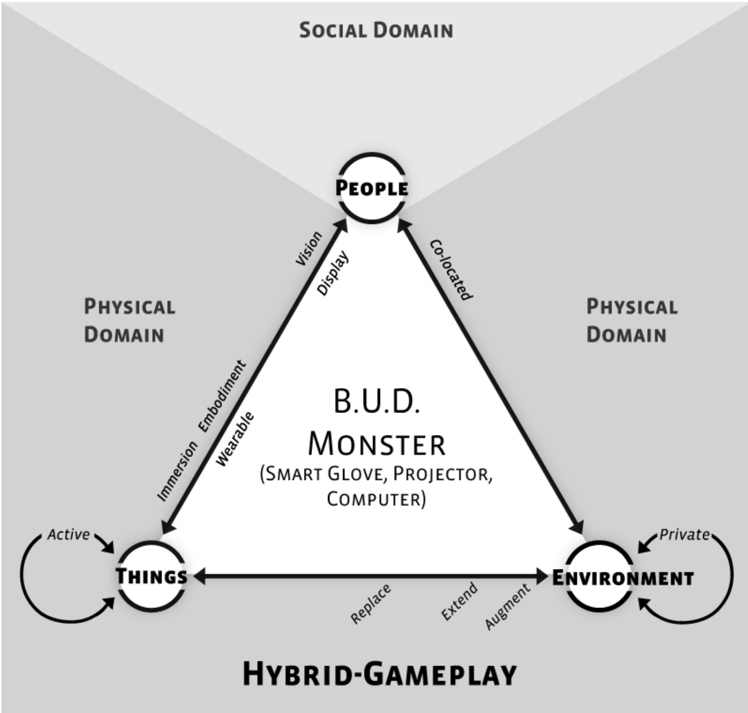

Figure 52 – Student's version of BUD Monster relational model.

Figure 53 – BUD Monster: a) virtual interface for player's view, b) users wearing smart glove during matches, c) the villain main tower, and d) destroyed buildings.

To provide immersion, a user *wears* a monster glove *augmenting* feedback of game actions. The *active* glove communicates with the system using Radio Frequency technology and provides both tactile and visual feedbacks. The glove *augments* character attacks vibrating a rumble motor, and special attacks flashing three LED displays.

The game goal is destroying the main enemy tower, but a player must destroy two shield generators first. All three targets located in different spots of a virtual map *visualised* in a projected *display*. A player *replaces* the character walking through the map, terrifying citizens, destroying buildings, and attacking army tanks. The number of enemies on-screen relate to destruction level held by the player. Hence, if the monster destroys too many buildings, a giant robot appears from the sky, and a user must defeat it.

The player *extends* game actions through gestures; these are melee punch, special punch, laser eyes, and monster roar. In the screen, a player can visualise monster's arms, and it is analogous to user's *wearable*. Also, during gameplay, a player can interact with several characters on dialogue boxes, as a monster boss, a city mayor, TV reporters, and the main enemy. The game ends when the monster destroys the central tower, or if an NPC defeats the player.

Forecastle (see Figure 54 and Figure 55) is an augmented board game inspired by the Great Navigations or the Age of Discovery. Three *co-located* players *compete* in a board, searching for gold and spices to returning to respective starting points. As *competition* is turn-based, the players take parallel actions during play.

The game setup consists of a large wooden boat enclosing a monitor *display* with a mast containing an attached camera connected to a computer. The computer allows an *IoT* connective field to enable transferring data to three *handheld devices*. Each player *manipulates* a *passive* boat figurine *replacing* player's cruisers enabling to explore a *shared* dynamic game-map on-screen.

Computer vision algorithm allows detecting ships using their colour information. Interacting with dynamic map key points, users can collect gold, buy spices, find trouble events (e.g., a sea monster attack), make repairs in their boats, or recruit crewmembers.

To interact with game events, users *manipulate active handheld devices* inside a *passive* treasure chest case. In the smartphone, each player has access to *private* augmented information, including a menu to perform game actions. Players receive *updates* of other players while they are taking a game turn such as he/she had experienced either a good or a bad event.

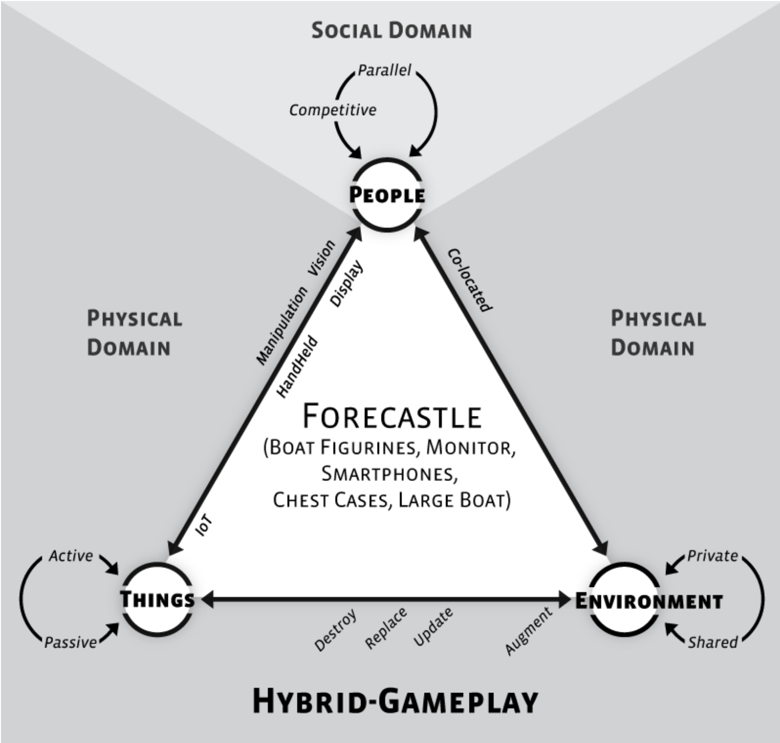

Figure 54 – Student's version of Forecastle relational model.

Figure 55 – Forecastle: a) boat figurines on the game map, b) augmented information on map, c) a smartphone inside the chest cover, and d) Forecastle team in an internal playtesting session.

Augmented game map information updates real-time such as the amount of coins and spices of each player. Besides key point interactions, a player may spy resources of other players, try stealing from them or *destroy* other player's boats attacking them.

Using crewmembers allows ships to perform special actions, such as take advantage on stealing resources, or creating adverse events to further competitors, such as sea storm. A gold piece acquires 1 point to players, and each spice unity 10 points, a winner is a player that has collected 100 points and managed to return to a starting point.

'Legends of the World' (see Figure 56 and Figure 57) is a hybrid arcade game

simulating battles of team monsters. Two *co-located* players *compete* in turns, and each player uses a *private* group of *passive* touchpoint figurines and a card deck, both embedded with NFC tags.

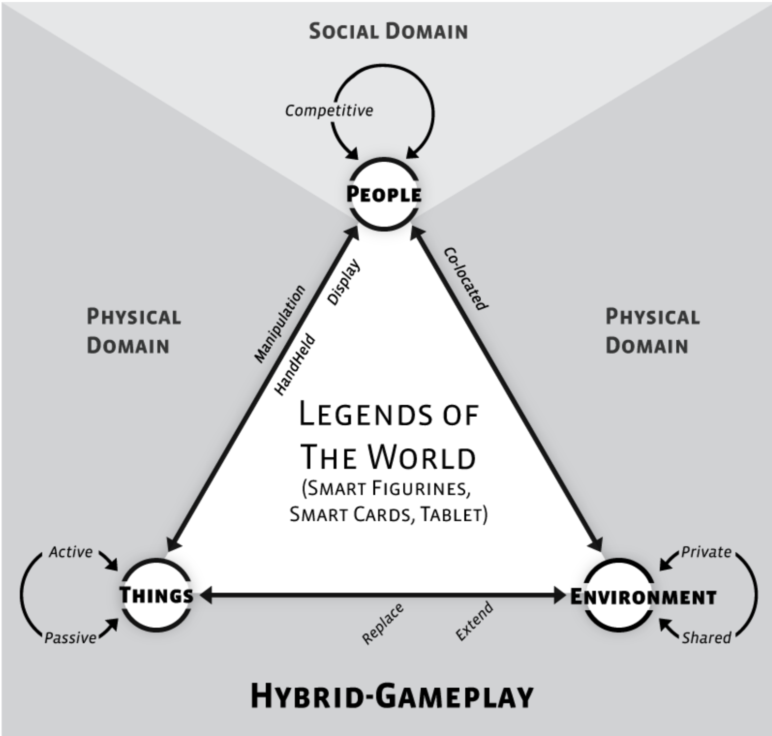

Figure 56 – Student's version of 'Legends of the World' relational model.

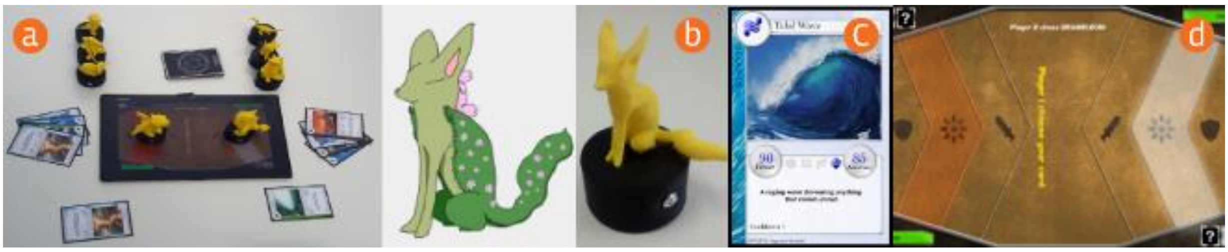

Figure 57 – 'Legends of the World': a) overall game setup, b) virtual replica and smart figurine, c) a power card sample, and d) the dynamic game arena highlighting neutral positioning.

The figurines *replace* monsters in the game arena, and using cards, players activate attack powers or may exchange monster during turns. Each monster creature has a race that may guarantee advantages and disadvantages among them. Each creature has specific abilities and features that may influence during battle. The player *manipulates* figurines in a *shared* active *handheld devi*ce, and tablet's screen *displays* feedback from game events, including available places on the game arena.

Game field presents three constraints allowing to influence on game events; these are defensive, attack, and neutral positioning. When a player places a figure in available constraints, it will change either attack or defence powers of cards. Each card action *extends* on screen presenting audio and visual feedbacks to players. A winner is a player that defeats opponent's monster team.

Stormstone RPG (see Figure 58 and Figure 59) is an augmented board game platform for RPG matches, inspired by the traditional paper-based experience. The pilot game is adventure themed, presenting a team of knights, wizards, and thieves, *competing* with goblins and skeletons in a dungeon. Each character is a passive metallic figurine enabled with touchpoints. Team players *collaborate manipulating* figurines in a *shared* monitor display.

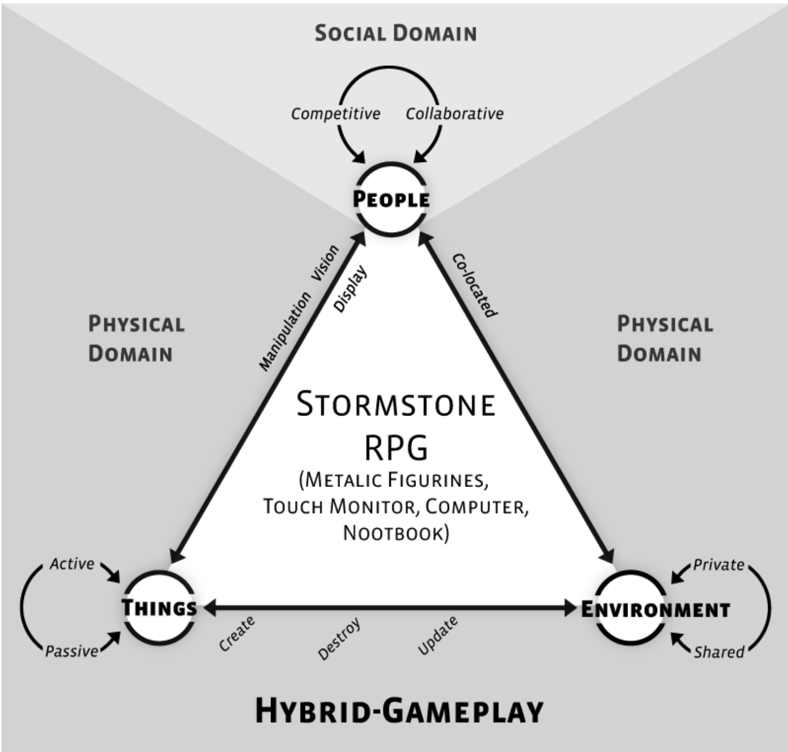

Figure 58 – Student's version of Stormstone RPG relational model. Source: The author.

A master player *manipulates* figurines of enemies and interacts with a *private* computer station. In master's interface, a player can *create* several game elements such as treasure chests and hidden enemies. Then, a master may *replicate* those in a shared game map. The game dungeon is hexagonal tiled presenting to the players the game elements and rules, such as available movement area for each player. A wizard, for example, may have a short action area but can perform a long distance attack. Team players take *parallel* game actions, such as attacking, moving, collecting items or destroying game objects.

Figure 59 – Stormstone RPG: a) virtual interface for Master Player, b) shared dungeon with touchpoint figurines, and c) a master customizing gaming map during playtesting sessions, along with metallic figurines view.

Master Player can *update* game information at any time. To performing game actions in the map, a player must take a turn, select an action in a virtual menu then touches the desired figurine to attack it, or select an item to collect it (*destroying* it). The master performs most game actions using a traditional mouse-keyboard interaction. A winner is either the entire group or the game master.

APPENDIX C – PLAYFUL SYSTEM MODELS

As mentioned in Section 4, in this appendix, we show 16 remaining descriptions & models of existing playful systems that we mapped during literature and market reviews. First, Camelot (see Figure 60 and Figure 61) is a *pervasive* indoor game where players *compete* and *collaborate* in teams, to *create* a paper castle, to do so, players must collect resources to obtain the castle pieces first (SOUTE et al., 2010). Participants *co-locate*, and each team has a *private* construction site, which consists of an *active* box containing automatic drawers. When a *parallel* player *extends* a collection of three *active* block resources on an *IoT* reader, it will *activate* the drawer, realising a *passive* castle piece.

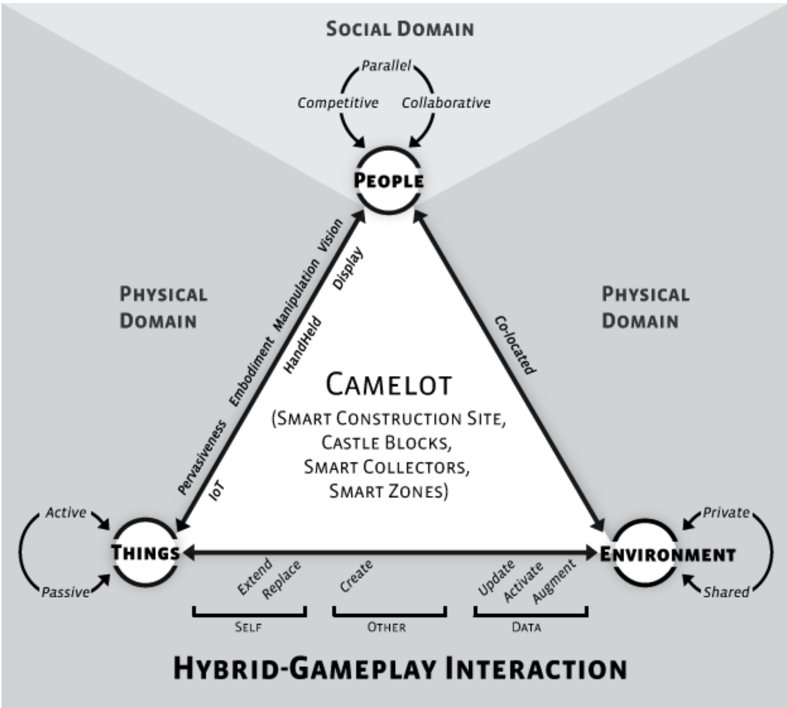

Figure 60 – IoT4Fun model for Camelot hybrid gameplay interaction.

Figure 61 – Children playing Camelot in a school environment.

Available resources are wood, water, and bricks; players can collect those *manipulating* a respective *handheld device*. Each smart collector has a colour and pictogram indicating sort of resource and those can keep one unit at a time. To collect a unit, a player must *extend* the collector upon a shared zone. Zones are *active* toys where a player can collect any resource by engaging *handheld devices* on it, once transferred a resource, the collector *updates* its inventory also *augmenting* such information on a LED display.

The zones located in different physical spaces and players through *embodiment* must move towards those to collecting resources. A *display creates* a random virtual ghost to increase the challenge, and when it appears, all players must run towards a monitor, and the last team to reach it loses all current resources. Also, players can exchange resources among teams, to complete the four game levels. Each level requires a different combination of resources, and the castle pieces are rewards for each level results. In this sense, wins the team that complete all levels and create a castle first.

ROXs (see Figure 62 and Figure 63) is a commercial platform for *co-located pervasive* games, destined to both outdoors and indoors scenarios (A-CHAMPS, 2016). The system consists of at least three *IoT* connected *handheld devices*, named ROXs. ROXs are *active* cubes containing a LED button *display* and enabled with RF communication protocol. The cubes allow connecting with each other including a controller where players choose among ten available games. Also, players can customise existing applications modifying their rules and feedback, hence creating new games.

ROXs modules can work inside *passive* belts, turning a *handheld device* into a *wearable*, making it more suitable to *embodiment* interactions. According to selected games, ROXs locates in either people or distributed in a large environment.

In Zombie Tag game, each player *wears* a belt with *active* ROXs on it; one player *replaces* a zombie character, and remaining individuals *replace* the humans. The zombie ROXs *augments* a LED *display*, so players visualise a representative colour also hearing "zombie" sounds.

The goal is to reach other players and *transform* their ROXs from human to zombie’s states, by *activating* LED buttons. When a player *manipulates* opponent ROXs, devices *update* passing from *private* information to a *shared* piece, the same happens when a player passes from a *competitor* to a collaborator. In this sense, the first zombie player may infect a second player, until they compose a team *transforming* all others, so the game ends when all players are zombies.

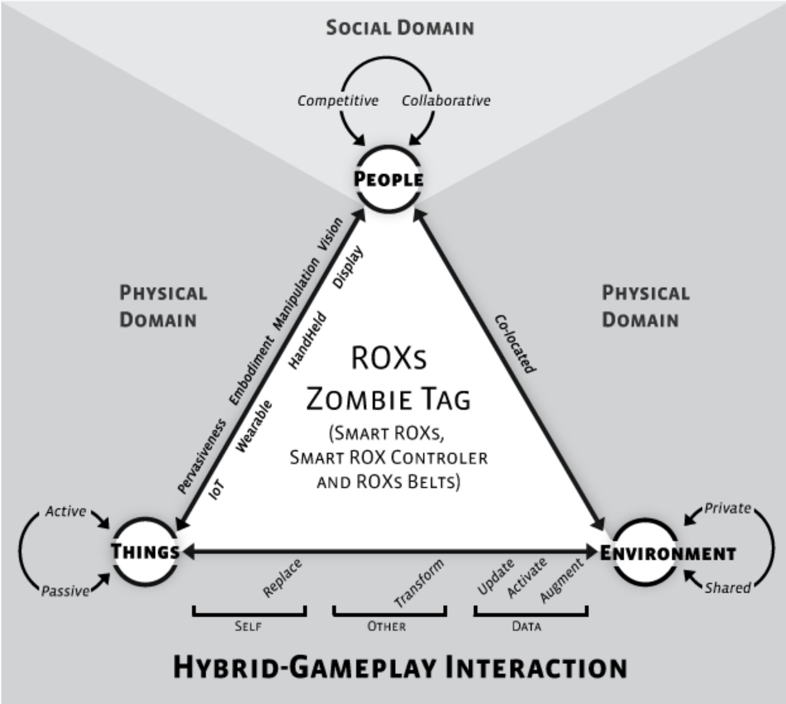

Figure 62 – IoT4Fun model for Zombie Tag hybrid gameplay interaction.

Figure 63 – ROXs system and children experiencing available games Zombie Tag and Crazy Chicken.

TacTower (see Figure 64 and Figure 65) is an exergaming platform to training handball players. The prototype consists of four *active* towers *IoT* connected to a computer station, enabling *embodiment* and *pervasive* interaction in different gameplay modes (FOGTMANN, 2011). Towers compose eight stacked plastic slots each containing a LED *display* inside, including sensors.

For all available games, players *share* a same physical environment. Also, each slot *replaces* the virtual game objects, and the four towers *extend* themselves transferring data between each other. All game objects *augment visual* information using colours from RGB LED *displays*. Thus, when a player touches a slot, it will *activate* game objects functions. Physical exertion level of games may regulate by changing distance between towers.

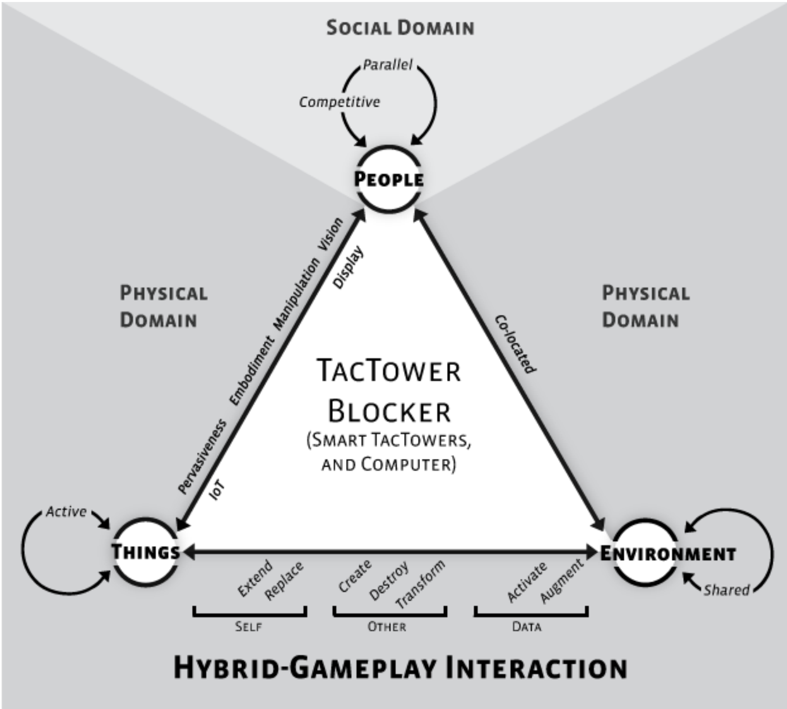

Figure 64 – IoT4Fun model for TacTower hybrid gameplay interaction.

Figure 65 – Two players competing, and a representative image of Blocker gameplay.

In Blocker game, two *co-located* and *parallel* players *compete*, so player one acts as attacker and player two as a defender. The attacker goal is to *transform* LED ball from initial position to a goal on the final tower, to do so, a player *manipulates* adjacent slots on either the same or a neighbour tower. The defender, or blocker, *manipulate* following same rules but *creating* one or two virtual blockers on selected slots. In this sense, if the ball collides with a blocker, it will *destroy* such object, and player one loses. Then, if attacker reaches the goal, the blocker player fails. At the end of each turn, players exchange roles to a consecutive match.

Fuzzy Flyers (see Figure 66 and Figure 67) is a commercial line of *active*, plush toys shaped like a ball, containing multiple positioning and movement sensors (FUZZY FLYERS, 2016). The toy line contains two game characters, and each one offers two *embodiment* games. Selecting plush dog Coco, a player may play Dance Party or Bark Attack. Choosing plush bird Chirpie, players can experience Sky Bird and Egg Toss games.

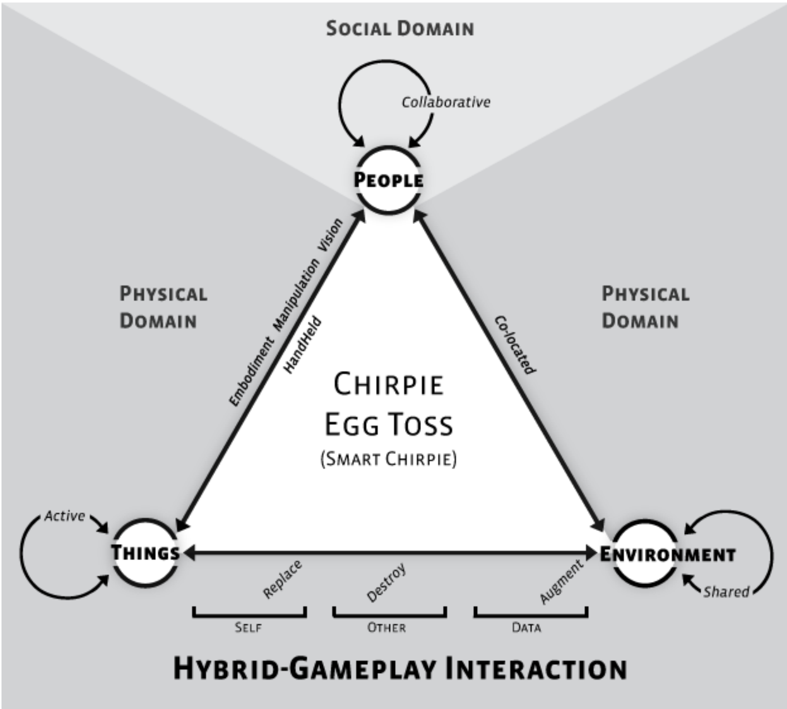

Figure 66 – IoT4Fun model for Egg Toss hybrid gameplay interaction.

Figure 67 – Children playing Egg Toss using Chirpie, and a girl playing Dance Party with Coco.

In Egg Toss game, two *co-located* players *collaborate* to avoid an ‘egg’ to break. They *share* a playful *handheld device* that *replaces* the ‘egg’ object, *manipulating* it and throwing it at each other. Chirpie sensors can detect speed and position, therefore *augmenting* through sounds if either movement was safe or if ‘egg’ broke. When players *destroy* the ‘egg’, the game is over, if they succeed a turn, each player has to move a step back, increasing the challenge for a consecutive match.

Beelight (see Figure 68 and Figure 69) is *active* toy shaped like a bee, enabled to transfer data to an *active* honeycomb (SHEN et al., 2013). The toy offers two *pervasive* play modes, a free-play experience of sharing a colour, so player uses Beelight to collect an environment colour and share it on the honeycomb *display*. Otherwise, in a colour-catching game, two or more *co-located* players *compete* to collect an *augmented* colour from the smart honeycomb.

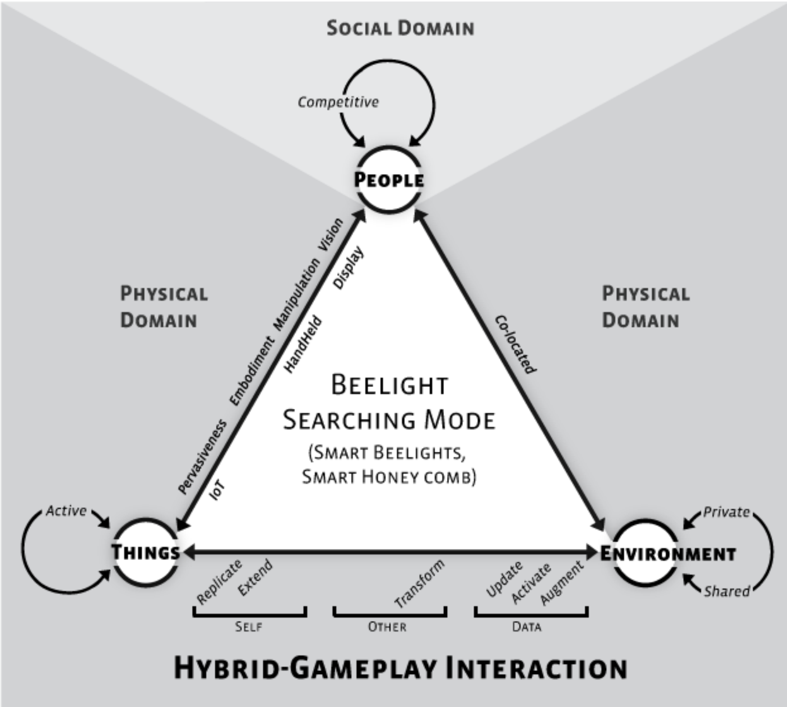

Figure 68 – IoT4Fun model for Beelight hybrid gameplay interaction.

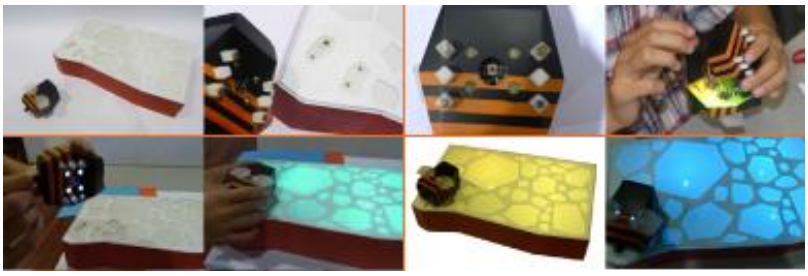

Figure 69 – Beelight system and interaction setup, and the honeycomb changing colours.

In this sense, players move around through *embodiment* and *manipulating private handheld devices* for collecting a required colour of environment objects. Then, when a player finds the desired colour, he/she places Beelight on the object's surface, *replicating* its colour information. Player *visual* accesses selected colours on a LED *display* located in the toy's wings.

After selecting the desired colour, a user may *activate* a button to *update* colour information in the toy. Hence, a player moves towards the *shared* honeycomb to *extend* Beelight data in a constraint first. Then, if *extended* colour is right, honeycomb *transforms* its displays, *augmenting* the next colour mission. In this way, one player wins in each turn.

DiDi (see Figure 70 and Figure 71) is a commercial toy line founded by a Kickstarter campaign, and it consists of plush cover toys for *handheld devices*, such as tablets and smartphones (WARREN, 2014). Each *passive* playful cover has an animal shape like a teddy bear, named DiDi or a rabbit called TuTu.

Covering IPad with DiDi plush case, it *replaces* game object turning a tablet into a "smart" bear. The cover splits the *display* screen in two, and upper section player *visualises* the bear's face while bottom *displays* dynamic game content and a storytelling application. To interact with DiDi as a *private* pretending play interaction, the *single* player *manipulates* touchpoint toys to *activate* game actions.

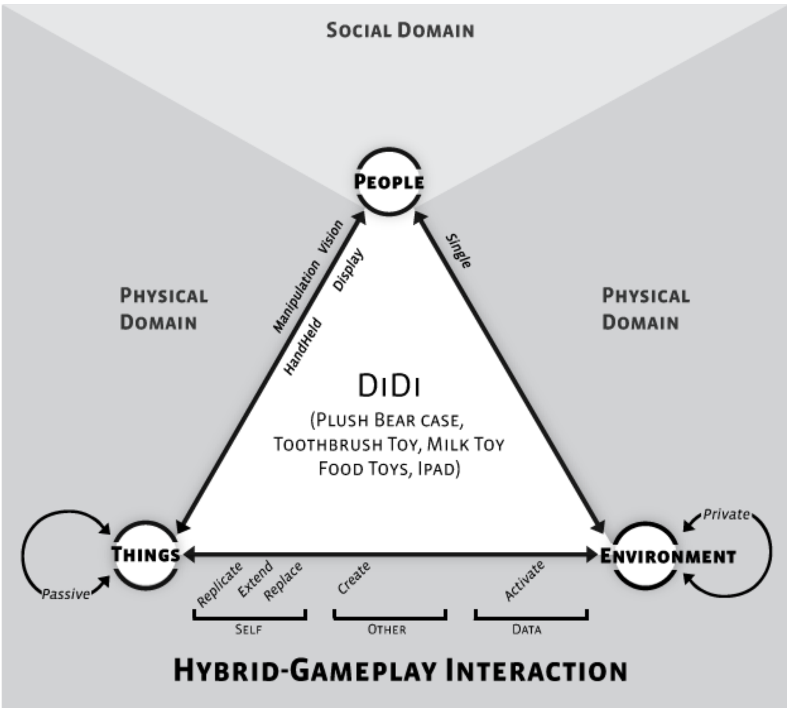

Figure 70 – IoT4Fun model for DiDi hybrid gameplay interaction.

Figure 71 – Prototype cycles of touchpoint toys, and system toy overview.

Available *passive* toys include a toothbrush, an apple, a carrot, and a milk-box. Toothbrush and milk-toy *extend* on the screen, *creating* respective virtual dental foam, and liquid milk. Food toys *replicate* on screen as virtual apples or carrots; which player can slice in a "digestion" mini-game. The hybrid gameplay interactions resume to mini-games related to each touchpoint toy, and storytelling system works as a playable tool but using touch-enabled interaction.

Toewie (see Figure 72 and Figure 73) is an *active* plush toy, cable connected to a computer application, *displayed* on a monitor (ABEELE et al., 2008). The playful *handheld device* has embedded sensors and actuators, enabling to control a virtual *replica visualised* in a 3D virtual world.

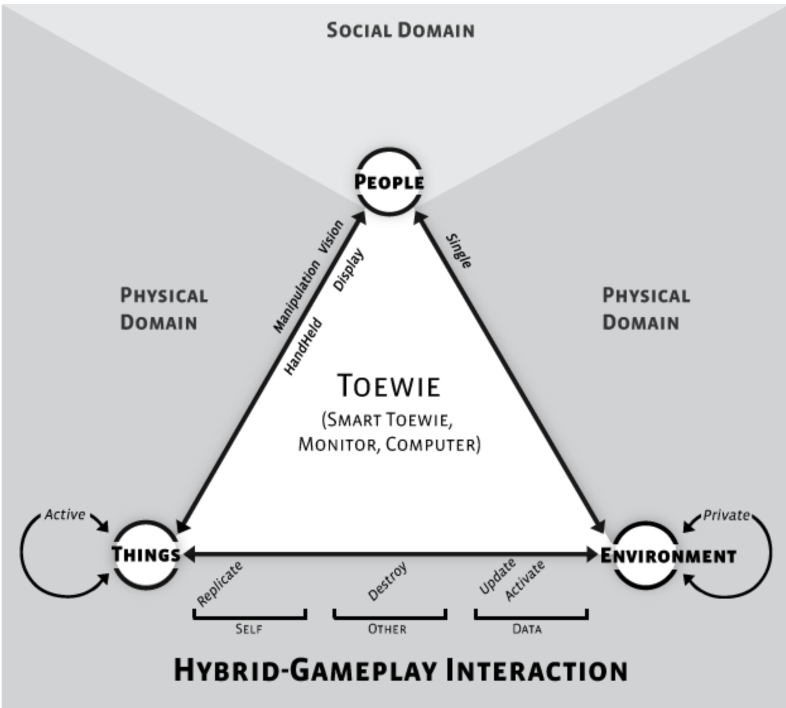

Figure 72 – IoT4Fun model for Toewie hybrid gameplay interaction.

Figure 73 – Toewie connected to its replica, and a comparative study setup.

In a *private* environment, the *single* player *manipulates* toy's arms and body to *activate* game functions of navigation, jumping and collecting items to adding in inventory. The main goal is to navigate *replicated* Toewie and collecting virtual gifts to a birthday party. Then, when *replica* gets close to the desired item, a player presses toy's arms *destroying* gift's objects in the environment. After *updating* seven gifts in inventory, the game is over.

Playmation Avengers (see Figure 74 and Figure 75) is a commercial line of connected toys and playful *wearable* for *pervasive* play interactions (HASBRO, 2015). Inspired by *Avengers* franchise from Disney, toys consist of playful hand gears assembling Ironman and Hulk aesthetics, enabled to interact with *active* figurines from several of Marvel characters.

All Playmation toys are *active*, and *IoT* connected using both long and short *distance* protocols. Those can connect with *handheld device*s, such as tablet or smartphone to *update* missions, and with each other during gameplay. In a *collaborative* game mode, two *parallel* players *wear private* gears to interact following level missions *augmented* in both tablet and *wearable*. Missions may involve interaction with *shared* villains and heroes' figurines placed on smart bases.

A player *wearing* Repulsor gear *activates* game functions by standing up his/her hands, so players may *extend* shooting towards figurines, *augmenting* audio and *visual* feedback, using speakers and LED *displays*. Then, a player *wearing* Gamma gear *augments* tactile feedback when *activating* punches through *embodiment* gestures, also *extending* attacks towards an enemy figurine.

To use help from a hero figurine, players *manipulate* such figurines, *extending* those in a fixed base. Each figurine *replaces* a character and has embedded NFC tags, which enable *active* base detecting those and *update* its state. In that way, during gameplay, the base *augments* sound and flashes LED *displays* to *extend* both released and suffered attacks. When a figurine loses all health points, system *destroy* those by throwing them out of the base. Each mission has its particular victory and failure conditions.

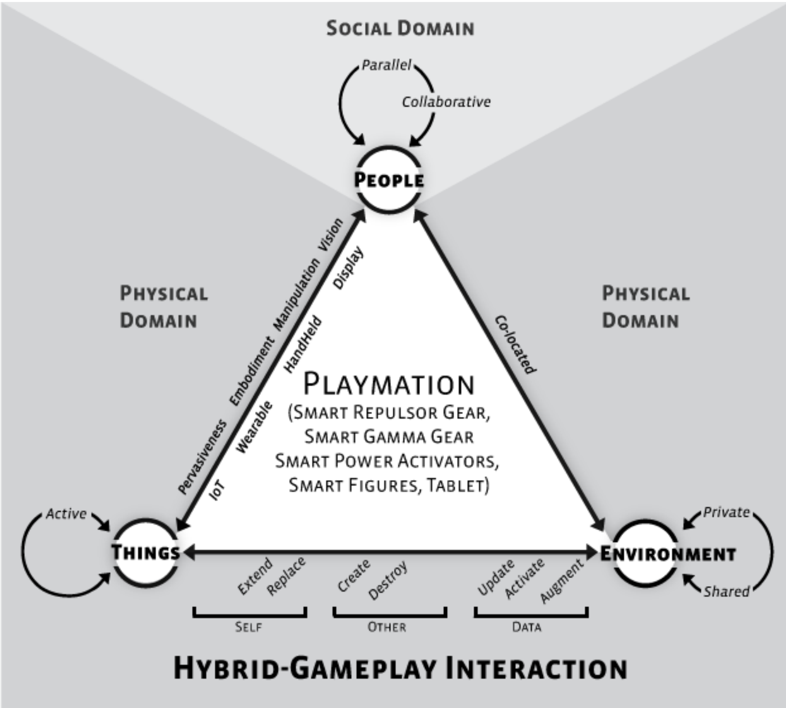

Figure 74 – IoT4Fun model for Playmation hybrid gameplay interaction.

Figure 75 – Different game modes for Playmation Avengers, and a connected smartphone.

Playcubes (see Figure 76 and Figure 77) is an *active* building blocks system connected to a gameful application on a monitor *display* (JACOBY et al., 2009). ActiveCubes have embedded components enabling sense each other, and their metallic structure allows blocks easy attach using magnet fields.

In a private environment, a *single* player *manipulates IoT* blocks to interact with a playground application including several mini-games. To *activate* games, a user must first build a *replicated* controller that matches with virtual shapes. In this sense, a player *visual* accesses practical instructions to *create* a playful controller using the cubes.

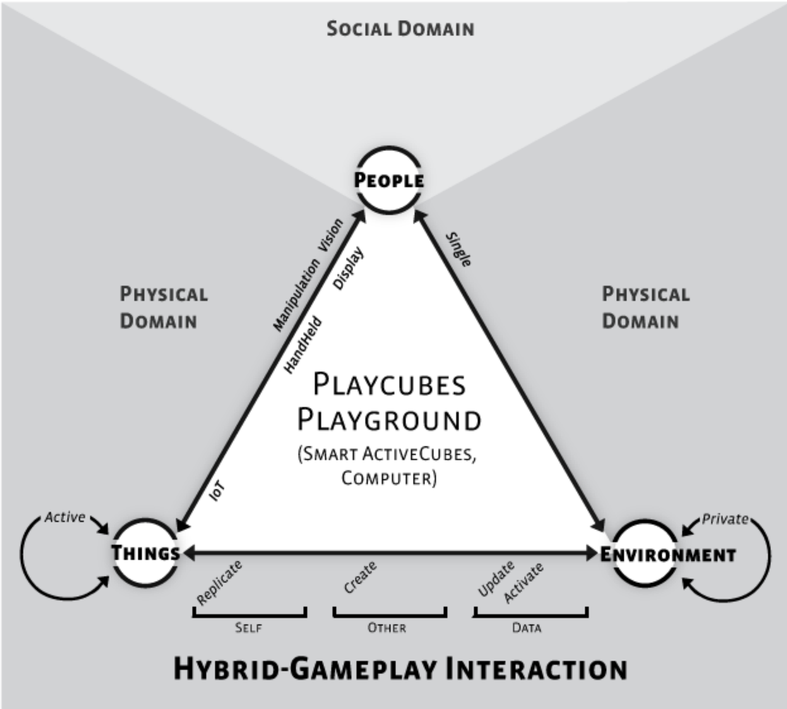

Figure 76 – IoT4Fun model for Playcubes hybrid gameplay interaction

Figure 77 – Playcubes physical setup and virtual application.

For example, to *activate* a dog character functions, a player first joint blocks to *create* a physical representation, then, system *update* such information, turning the virtual object into a *replicated* interface. In that way, a user may play a game, *manipulating* toy interface to moving a *replicated* virtual dog looking for a treasure chest in a maze.

Furby Connect (see Figure 78 and Figure 79) is a commercial product line of plush-robotic toys (HASBRO, 2016). Furby is an *active* toy with embedded electronic components that allows communicating with *handheld devices*, such as tablets and smartphones, using BLE protocol. Furby *augments* audio, *visual* and tactile feedback to several physical *manipulations* like shaking, squishing, or either pulling its tail.

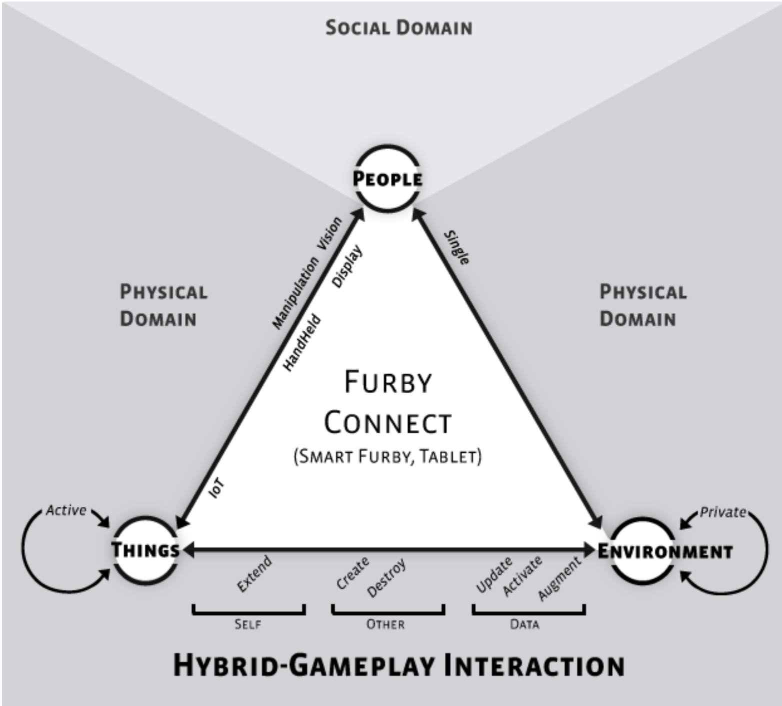

Figure 78 – IoT4Fun model for Furby Connect hybrid gameplay interaction.

Figure 79 – Furby Connect: toy robot performing physical feedbacks, a user pressing toy's body, a screen-shot of food application, and Furby sleeping.

When *IoT* connected to a *single* player application, a user may interact with mini-games and multimedia content in a *private* environment. Two applications are pretending play situations these are feeding and using the bathroom. In both games, the player *manipulates* Furby to *activate* and *extend* game actions, such as when pressing toy's body, it *creates* random game objects on screen *display*, i.e., a toy car or a pineapple.

In food application, a user may select ingredients in a virtual blender, and then extend such food out screen towards Furby's mouth. Furby *destroys* the food when eating it and toy *augment* corresponding physical movements and sounds. Sometimes, if the character finds the food taste unpleasant, it will throw food away, *extending* it back to screen.

After every interplay, system *update* toy-robot state, recording such information in both toy and application. In that way, interaction cycles restart when toy requires maintenance of game stats. Remaining interactions regard *augmented* reactions when player interact with the application, such as watching internet videos or collecting virtual eggs and mini-Furbies.

Rope Revolution (see Figure 80 and Figure 81) is an arcade installation with four hybrid games using a physical rope interaction (YAO et al., 2011). The station consists of a wall containing an *active* box embedded with motors and sensors connected to a *passive* rope, attached to a *handheld device*. System *augments* virtual environment physics by pulling or realising force on a physical rope. A Wii Mote controller allows a cord to *extend* its movements *visually displayed* on a wall projection.

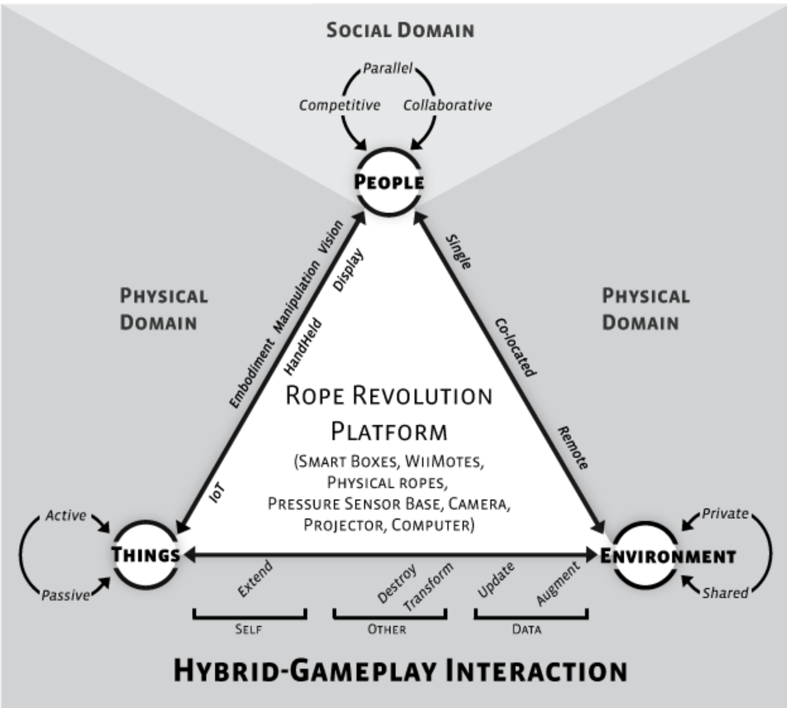

Figure 80 – IoT4Fun model for Rope Revolution hybrid gameplay interaction.

The physical rope *extends* itself connected to several game objects in different game modes; these are a kite, a horse, a sawing, and a three. In Kite flying game, a *single* user or two *co-located* users *compete transforming* the position of a connected virtual kite. Playing Horse Driving, a *single* player controls a horse jumping on obstacles, *transforming* its position, and avoiding *destroying* virtual obstacles. In sawing application, single player destroys virtual logs of wood when manipulating physical rope.

Figure 81 – Two players competing in 'Flying a Kite' game, a screenshot of available games, and people interacting with the system.

In rope jumping, a single player interacts with a virtual frog jumping on an extended virtual rope connected to a three. Another game mode, consist of two *remote* located players *collaborating* in *parallel embodiment* interactions, i.e., player one *manipulates* the rope and other jumps on an *active* base. Base keeps *updates* of player's position, such as when he/she is jumping or standing on the floor. In that way, Rope Revolution system offers either *private* or *shared* environment information.

Pokémon GO Plus (see Figure 82 and Figure 83) is a *wearable* accessory for a *pervasive* mobile game named Pokémon GO (NIANTIC, 2016). Pokémon GO is a geo-location based game, where users interact with virtual stops and creatures while located in a real outdoor environment. Game interactions happen essentiality on a *handheld device*, so using the *active wearable* user may engage in tangible interaction, *activating* most of the in-game actions. Players may *wear IoT* accessory attached to their clothing or using a *passive* wristband.

The device has a shape of a geo-location pin assembling a "Pokéball" aesthetics, containing a *LED* button *display* to both *extend* actions and *augment* information. List of available *extended* actions includes collecting (*destroying*) items in virtual stops and releasing (*creating*) balls to catching creatures. The device keeps track of *embodiment* information, such as walked distance sending such information to the connected application, aiding in hatching eggs and collecting candy items. Also, Pokemon Plus have access to other player information such as inventory state, and catalogue of known creatures.

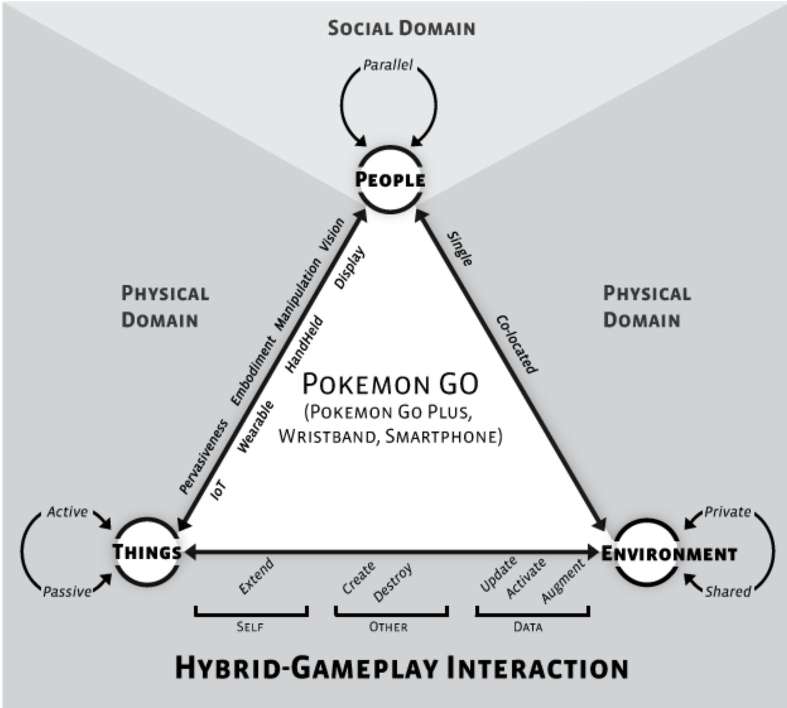

Figure 82 – IoT4Fun model for Pokemon Go hybrid gameplay interaction.

Figure 83 – Pokemon GO Plus connected application, a user activating wearable button, and another wearing it on his clothing.

Visual augmented feedback corresponds such game events, and these divide two groups of information, first in a response of activating *private* game actions, second to presenting *shared* environment information. *Private* actions correspond to those related to each player's profile; these are collecting creatures and items in stops, i.e., green indicating a presence of known creatures; red augmenting that a creature has run away; flashing white *augmenting* 'catching a creature' state, and white showing a full inventory.

Shared information is available to all *parallel* players, such as *augmenting* blue to a proximity of a virtual stop, and a presence of either known or new creatures. *Parallel* users may play "together" while *co-located*. Despite *shared* environment information, the system does not support communication between players. In that way, the system works as a *single* player application in many actions.

ChillFish (see Figure 84 and Figure 85) is a serious game destined to anxiety therapy, where a single player in a private environment, manipulates a playful handheld device (SONNE & JENSEN, 2016). LEGO fish-toy has embedded components such as a breath sensor, also enabling IoT connection using a Bluetooth protocol. Active toy collects embodiment information to activate game functions, so when a user exhales into fish-toy a replicated fish swimming up, when inhaled, fish swims down.

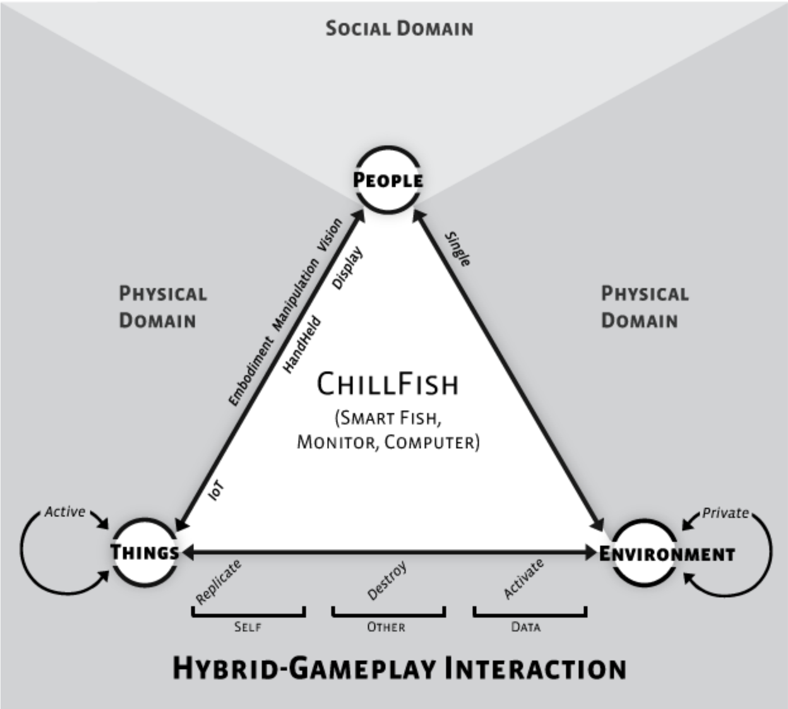

Figure 84 – IoT4Fun model for ChillFish hybrid gameplay interaction.

Figure 85 – A user experiencing ChillFish, and fish toy made of LEGO bricks.

Replicated fish swims in a 2D virtual environment visualised on a screen display. The game is an endless runner, and the goal is collecting ocean stars as much as possible, destroying those in the game world. The game is over at a given time.

PuzzleTale (see Figure 86 and Figure 87) is an interactive storytelling system where a *single* player *manipulates passive* puzzle pieces in a *private* tabletop (SHEN et al,, 2010). The playable tool tells a dog story, and according to an order of selected constraints, a player experience different plot keys.

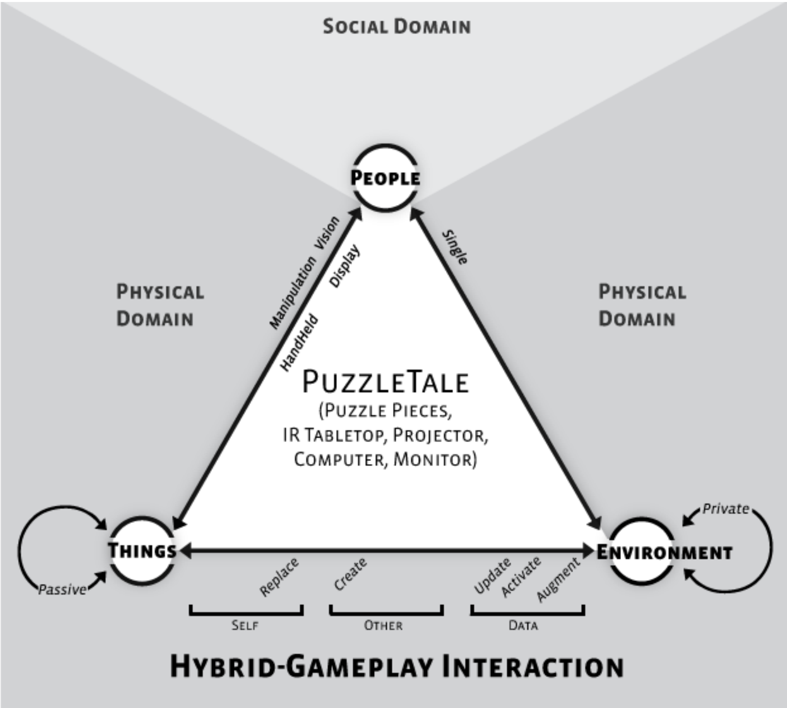

Figure 86 – IoT4Fun model for PuzzleTale hybrid gameplay interaction.

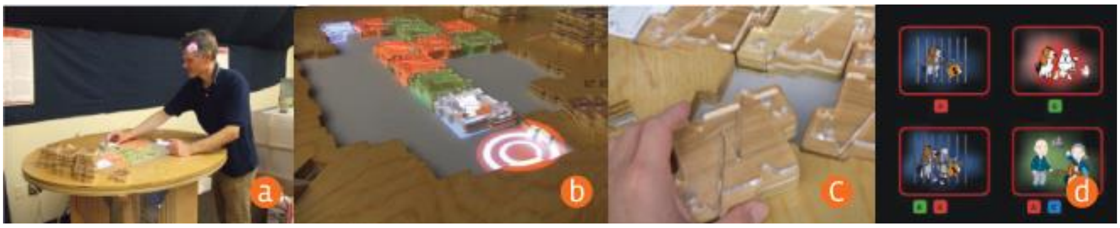

Figure 87 – A user placing pieces on the tabletop, and overview of system setup, including a screenshot of plot variations.

Tabletop has an IR camera allowing read *passive* fiducial makers on the bottom of jigsaw puzzle pieces. Puzzle pieces *replace* the dog character, and a projector *displays* virtual characters on a tabletop. Then, when a player places a piece into a constraint containing a virtual figure, it *activates* a game event. An additional monitor *display creates* corresponding *visual* animations *augmenting* selected key plot elements.

The story goal is lead a dog to its home, during path a player may interact with a female dog, an old couple, and a dog shelter. The system *updates* order of selected game events, resulting in different endings.

Oniri Islands (see Figure 88 and Figure 89) is a project funded on Kickstarter, and it is an RPG adventure and exploration hybrid game (TOURMALINE STUDIO, 2017). Two *co-located* players *collaborate manipulating private passive* toy figurines in a *shared handheld device*. Toys *replace* two game characters enabling them to interact with a virtual scenario and other game objects. Toys are made of conductive plastic allowing using touchpoints patterns and recognizing *passive* masks placed on them. Attaching masks into characters, *transforms* them *updating* power-ups.

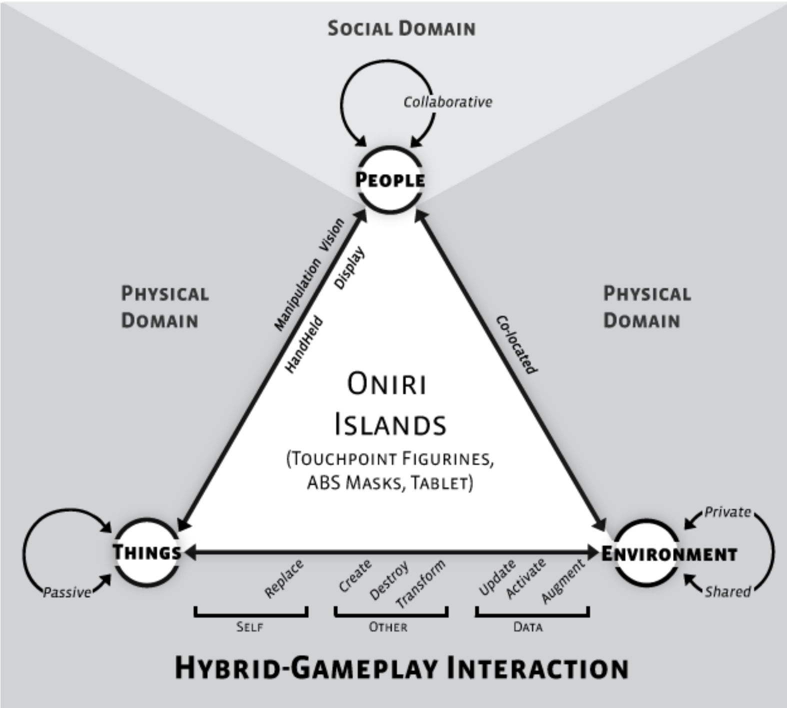

Figure 88 – IoT4Fun model for Oniri Islands gameplay interaction.

Figure 89 – Overview of system setup, two users playing a collaborative experience, and a figurine with and without an ABS mask.

The gameplay consists of exploring the map in a sequence of quests, and during path, players may *create*, *destroy* and *transform* several game objects, i.e., conjuring power-ups, extinguishing a virtual fog, and moving sea stars. Hence, *collaboration* requires sometimes two moving axis points from both toys. Players activate game in-game actions by either sliding or taping on-screen *manipulating* toys. Also, tablet's *display augments visual* feedback such as characters' position and related game information. Game system progress and players initiate and finish quests as a sequential interaction.

Don't Panic! (see Figure 90 and Figure 91) is a hybrid version of inspired by existing board game containing both *active* and *passive* tokens (MORA et al., 2016). A *shared passive* map dived a city in sections, and each section has a population number and a related panic level. Four players *collaborate* managing the panic state of sections *manipulating active handheld devices*.

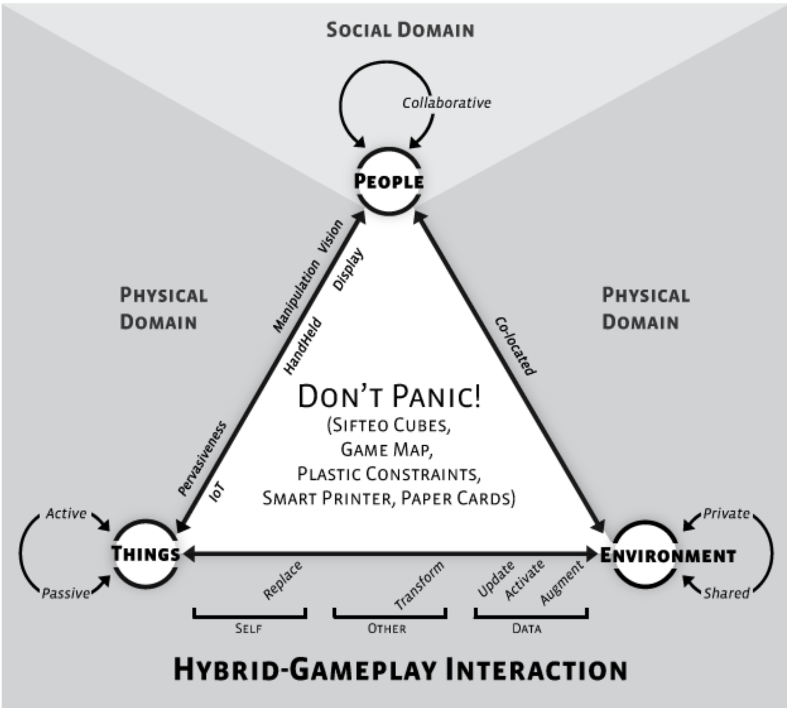

Figure 90 – IoT4Fun model for Don't Panic hybrid gameplay interaction.

Panic level constantly *updates* during gameplay and may increase due interaction with random events. An *active* printer, *create* random events *replacing* those with passive bar code cards; also printer has embedded reader enabled to detect card information, *updating* the panic level.

Figure 91 – The game map, active and passive tokens, and the printer.

There are *passive* plastic constraints to place active Sifteo cubes, and *IoT* cubes *replaces* different game functions. First, pawn cubes *augment* static information such as each player is responsible for a sector, and *updatable* information such as such as population number, and its panic state.

'Calm!' cube *activate* the game function of decreasing panic level, and 'Move!' cube *transforms* people from a sector to other increasing and decreasing population number. Moreover, both cubes *augment visual* and auditory feedback of game events. In that way, four players *collaborate* managing citizens according to regular changings of the panic level, and in reason of random events. The team wins when all panic levels are equal to zero.

APPENDIX D – WORKSHOP RESULTS

In the present Appendix, we showed four remaining descriptions and models from the workshop concepts, mentioned in Section 4. First, *AR Detective* (see Figure 92 and Figure 93) is a *competitive co-located* game between two or more *parallel* players, supporting *collaboration* among detective players. Gameplay consists of a thief player committing a crime by selecting it on a *handheld device* application.

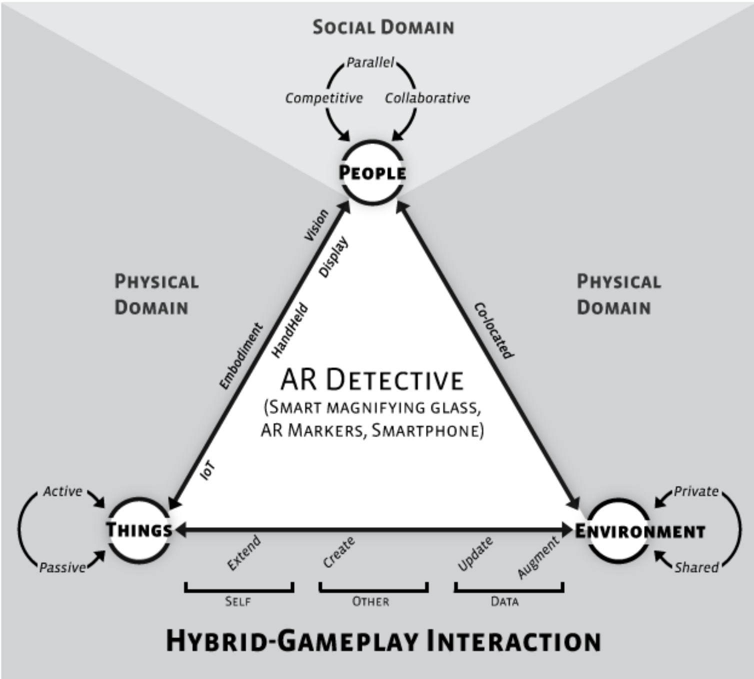

Figure 92 – A relational model for AR Detective hybrid gameplay interaction.

Figure 93 – AR Detective relational model document along with a paper prototype.

After choosing a crime, a player must choose *passive* AR markers to *create* either correct or wrongful clue to solve the crime, and this information is *private*. Then, thief player may hide those in a physical environment. Later, through *embodiment*, one or more detective players use an *active* magnifying glass to search and *augment* hidden clues.

Each detective holds a *private* smart tool enabling connect with a smartphone using *IoT* technology. When a player finds a *shared* marker, tool *extends* lenses *augmenting* clue information; players can *visual* access to data in both tool and phone *displays*. When a player collects at least two *augmented* clues, system updates, so he/her may risk a solution or continue to play. Detectives win either if player or team claim a correct solution, so, a thief wins if detective makes a wrongful answer.

Tangram 3D (see Figure 94 and Figure 95) is an arcade game suitable for both *single* player and multiplayer, including *competitive co-located* game and *remote* mode, then the environment is either *private* or *shared*.

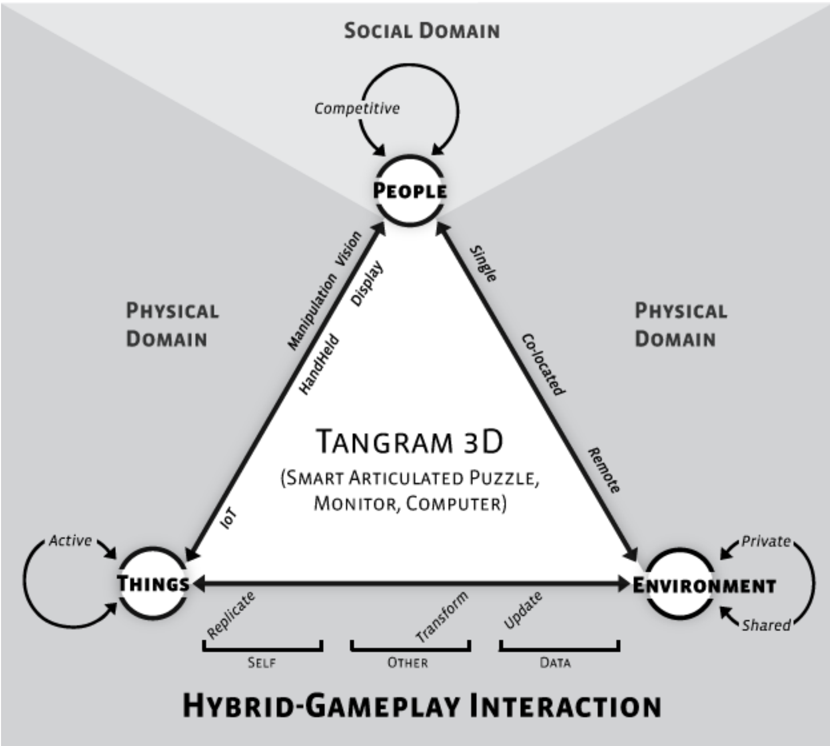

Figure 94 – A relational model for Tangram 3D hybrid gameplay interaction.

Gameplay consists *manipulating* a playful *handheld device*, which is an *active* articulated puzzle able to detect the position of its parts. In this sense, players visual access a *replicated* artefact in an on-screen *display*, which *replicates* performed physical movements. Players also receive tactile feedback through a vibrating motor.

Figure 95 – Tangram 3D relational model document along with a paper prototype.

The goal is to reach from starting point to ending point in a 3D virtual environment. Thus, players must articulate toy, avoiding *replica* to touch any of virtual obstacles. Then, player *transforms* game object while *manipulating* it, and if virtual *replica* collides with other game objects, it will damage it, therefore, *updating* game state such as current HP. Player succeeds when completing a level and fails loosing health points, when touching the obstacles.

Painful System (see Figure 96 and Figure 97) is a hybrid arcade *single* player game with horror and mystery thematic, so the environment is *private*. Gameplay consists of *manipulating* a playful handheld device, which is an *active* Rubik's cube able to sensing position of its parts allowing detecting each of cube's face.

Figure 96 – Painful System paper sheet model, paper prototype along with details of 'smart' Rubik's cube, and replicated paper display.

In this sense, players *visual* access a *replicated* cube in an on-screen *display*. The goal is to use a cube to open virtual doors in a 3D environment; so in each door, system *augments* puzzle keys to players perform using the cube. Then, when a player completes a correct combination, it *activates* game functions, therefore *transforming* the virtual doors while opening those. Players also receive tactile feedback through a vibrating motor.

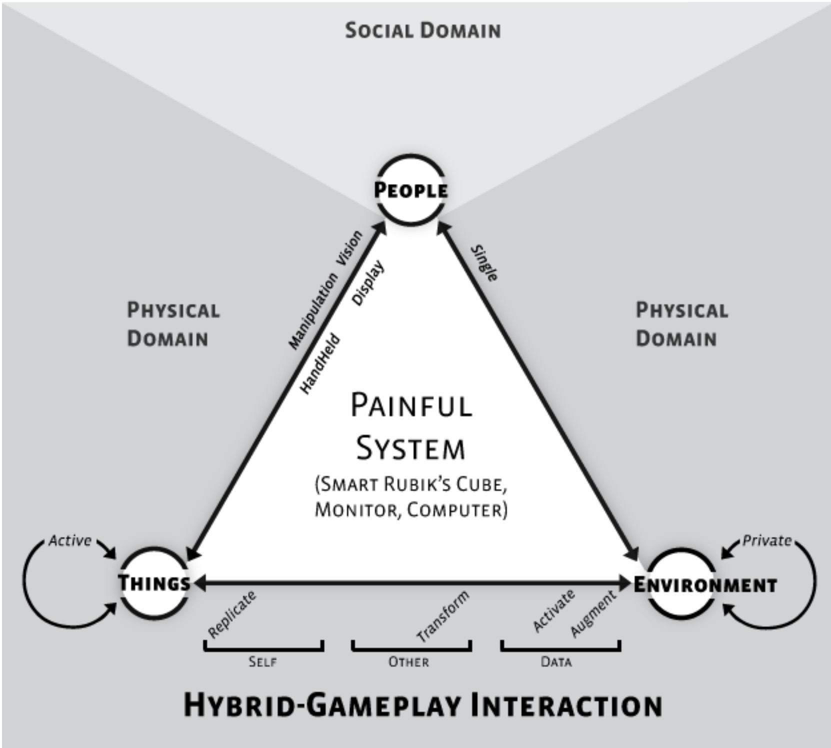

Figure 97 – A relational model for Painful System hybrid gameplay interaction.

BYG (see Figure 98 and Figure 99) is a hybrid arcade game with *single* player or *competitive co-located* mode. In *single* play, a player *manipulates active* building blocks able to *update* and detect each other. System, however, detects block set using their colour information through a camera attached to a monitor. Players place blocks *transforming* a virtual character position in a 3D environment. The goal is leading character to reach ending level placing *replicated* platforms on the screen display.

Each colour represents a corresponding platform blue indicates a walking platform, yellow a jumpable, and red a platform allowed attacking virtual enemies. If a player places a block up to other, this will *update* system, increasing game actions effects, such as doubling power attack or walking speed.

System *augments* required blocks for each level. Thus, when player set a sequence of blocks, it may *replace* a path to a character complete a level. In *competitive* mode, one player may place virtual obstacles to opponent solve proposed level design. Player succeeds if he/she completes a level, and fails by either dropping the character from a platform or suffering total damage from level enemies.

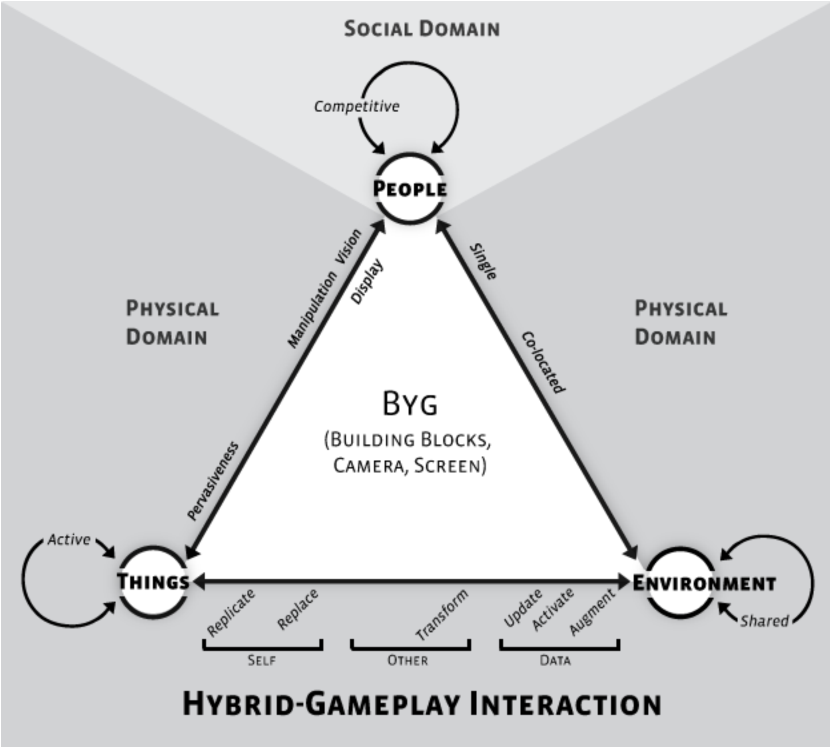

Figure 98 – A relational model for BYG hybrid gameplay interaction.

Figure 99 – Participant working in her paper prototype, and low-fidelity prototype with respective paper sheet model.