

# A heuristic design grid for past and future uses of Token+Constraint systems

Stéphanie Rey<sup>1</sup>, Anke M. Brock<sup>2</sup>, Brygg Ullmer<sup>3</sup> and Nadine Couture<sup>4</sup>

<sup>1</sup> Berger-Levrault, Toulouse, France

<sup>2</sup> ENAC, Université Toulouse, Toulouse, France

<sup>3</sup> HCC Division, School of Computing, Clemson University, Clemson, South Carolina, United States

<sup>4</sup> Univ. Bordeaux, ESTIA INSTITUTE OF TECHNOLOGY, Bidart, France

## Abstract

The “token+constraint” (T+C) paradigm for tangible interfaces was introduced almost twenty years ago. To what extent has this paradigm been engaged in practice? We conducted a systematic literature review of the articles citing the original T+C paper. Approximately 30% of these works actually implement a tangible constraint. We also observed that it was difficult to analyze the adequacy of a system with the T+C paradigm. Hence, we propose a heuristic grid that gathers, synthesizes, and simplifies the design guidelines and benefits mentioned in the original T+C article toward enabling others to design, develop and evaluate systems that take full advantage of the T+C concept.

## Keywords

Tangible user interface; token+constraint interfaces

## 1. Introduction

In 2005, Ullmer, Ishii, and Jacob [1] classified tangible user interfaces (TUIs) into three main (non-exhaustive) types: “*interactive surface*” where users manipulate physical objects on digitally augmented flat surfaces; “*constructive assembly*” which uses modular elements for instance inspired by LEGO™-like objects; and “*token+constraint*” (T+C). Tokens are defined as “*discrete physical objects which represent digital information*”, and constraints as “*confining regions that are mapped to digital operations*”, and which are “*frequently embodied as structures that mechanically channel how tokens can be manipulated, often limiting their movement to a single degree of freedom*”. Further it is defined that “*placing and manipulating tokens within systems of constraints can be used to invoke and control a variety of computational interpretations.*”

The first two categories are often used for geometric or spatial representations, while T+C particularly supports interaction with “*abstract digital information that has no inherent physical representation nor any intrinsic physical language for its manipulation*”. T+C interfaces have interesting properties such as engaging kinesthetic awareness and passive haptic feedback, thus prospectively reducing visual load of the person interacting with the system. This article attempts to engage two research questions: What is the impact of the *token+constraint* paradigm in the realization and experimentation of published tangible prototypes for the 15 years interim (2005 – 2020)? How can the structural and functional nature of a *token+constraint* prototype best be characterized, and how can one measure the degree to which systems engage the proposed benefits for such paradigm?

## 2. Systematic Literature Review

We conducted a systematic literature review (SLR) [2] toward understanding what published instantiations have explicitly employed the *token+constraint* interaction paradigm. For this purpose, we considered all articles citing

---

Proceedings of ETIS 2022, November 7–10, 2022, Toulouse, France

EMAIL: stephanie.rey@berger-levrault.com (A. 1); anke.brock@enac.fr (A. 2); n.couture@estia.fr (A. 3); bullmer@clemson.edu (A. 4)

ORCID: 0000-0002-2826-2489 (A. 1); 0000-0002-0017-396X (A. 2); 0000-0003-0925-2303 (A. 3); 0000-0001-7959-5227 (A. 4)



© 2022 Copyright for this paper by its authors.

Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

CEUR Workshop Proceedings (CEUR-WS.org)

the original TOCHI article [1] in Google Scholar, as of June 29, 2020. We then filtered the articles not in English (24 articles), without peer review committees (40), with duplicated content (37), without tangible interactive system (theoretical model or not TUI-centric) (51) and 15 errors (no citation or not found). This reduced the number from 255 to 88 articles (see Appendix A1 for a complete list of references).

We then considered the 88 resulting systems from the perspective of the *T+C* interaction paradigm. 26 articles introduce prototypes which instantiate at least one tangible constraint in their examples. This 30% ratio stems from *T+C* article been mainly cited as a taxonomy of TUI, sometimes instead of or in combination with MCRit [3] and TAC [4]. Eleven articles describe technologies to implement TUI using toolkits [5]–[7], new sensing technologies [8]–[10], or by instantiating generic reusable tangible widgets [11]–[15]. The 15 remaining articles are application use cases for professional uses [16]–[19], teaching purposes [20]–[23], domestic uses [24]–[28], for children in a library [29] and for a group of visitors in a museum [30]. We classified the citations of the *T+C* article according to Girouard et al. [31] (high-level citation means the cited work has a direct influence; low-level citation helps lay a foundation of the work, but its omission would not be critical; see coding in the second column of the table in Appendix A2). We observed that technology-driven works made full use of the *T+C* concept, and sometimes even enhanced it: seven high-level citations modulated by the inclusion of two of Ullmer's subsequent articles, three medium level and one superficial citations (see A2). Altogether more than half of the use cases seemed to draw at least partial motivation from *T+C* (nine high-level, four medium level and two superficial).

The original *T+C* article discussed constraints as prospectively realizing physical expressions of digital syntax. Regarding this, most prototypes (17 out of 26) allow the manipulation of abstract data, i.e. data which is neither geometric nor spatial. *T+C* interaction can be composed of two phases: the association phase, where the user places the token in the constraint; and the manipulation phase, where the user manipulates the token inside the constraint. The majority of prototypes used only the association phase of the *T+C* paradigm (17 out of 26, and even 13 out of 15 for concrete use cases), in contrast with the original article's anticipations of a greater use of the manipulation phase [1]. Six prototypes use a single constraint [13], [16], [21], [25]–[27], and thus it could be argued that they employ a limited syntax of use. Five prototypes use loose constraints [7], [18], [21], [25], [26] and thus arguably make weaker use of the constraints concept. A large constraint size compared to the size of tokens results in less passive haptic feedback. Moreover, if constraints are much larger than tokens, it is harder for the users to identify which tokens and constraints match since compatibility of tokens and constraints is expressed through their shapes.

Since we observed an interest for *T+C* in the SLR, and given our optimism regarding the benefits listed below of *T+C* systems, we revisit the original article [1] as a heuristic grid. We believe existing and future prototypes employing this approach, and associated grid as guideline, can be enriched by this in-depth analysis of their relationship to the *T+C* paradigm.

### 3. Heuristic Design Grid

To derive a heuristic design grid, we systematically identified the properties listed in the original article [1]. We focused on the sections describing the paradigm (*ibid.* section 2), the benefits (*ibid.* section 2.3) and the *T+C* approach from the perspective of the five questions of Bellotti et al. [32] (*ibid.* section 5).

Section 2 (*ibid.*) describes the different components of the *T+C* concept. From this, we can identify core and peripheral properties related to the general composition of the *T+C* systems (Table 1, "General composition" in yellow, properties pg1 to pg6). We have defined as core the properties stated without conditional terms such as "may", "can" or "often" (marked with "\*" in Table 1). We suggest that a prototype can be regarded as a *T+C* system if it fulfills all core properties.

Section 2.3 (*ibid.*) further lists a set of benefits related to the embodiment of numeric syntax (Table 1, "Syntax" in blue). The physical forms of constraints convey the compatibility between information (tokens) and digital operations (constraints) (ps1). They also restrict the possible placements of tokens to a limited number of configurations with defined meanings (ps2). Finally, the clear delineations of the constraints indicate the different algorithmic functions (ps3). Section 2.3 continues with a list of usage and implementational benefits, allowing us to supplement Table 1 with the sections "Interactions" (green), "Implementation" (orange) and "Use" (grey). In the "*Human perception*" section in [1], authors indicate that constraints facilitate the externalization of cognitive load. To rephrase this property, we refer to section 3.2.1, which explains the usefulness of exploratory actions (as

**Table 1:** T+C heuristic grid applied on Prim Box (PB) and Tokens of Search (ToS) (v: yes,  $\chi$ : no).

	Core	PB	ToS
<b>General Composition</b>			
Pg1	The interface presents at least one mobile physical object (token).	*	√
Pg2	A token embodies digital data.		√
Pg3	The interface has at least one mechanically restricted area in which a token can be placed (constraint).	*	√
Pg4	A constraint embodies a digital operation.		√
Pg5	The user can place a token in a constraint (association). This association is interpreted by the system.	*	√
Pg6	The user can manipulate a token within a constraint along a single DOF (translation, rotation). This manipulation is interpreted by the system.		$\chi$
<b>Syntax</b>			
Ps1	The interface uses the physical characteristics of the constraints (such as shape and size) to indicate which tokens are compatible.		$\chi$
Ps2	The interface uses constraints to mechanically limit the possible token configurations.		$\chi$
Ps3	The different algorithmic functions are embodied in separate constraints.		√
Ps4	The interface allows to group tokens and constraints to form patterns		$\chi$
<b>Interactions</b>			
Pc1	The constraints of the interface use passive haptic feedback.	*	√
Pc2	The interface uses active force feedback.		$\chi$
Pc3	The interface allows interactions not detected by the system.		√
Pc4	The interface allows to manipulate several tokens at the same time.		$\chi$
Pc5	The area of interaction is clearly defined by constraints.	*	√
Pc6	The interface uses additional feedbacks (audio, visual, haptic) for each entry, exit and/or token movement within a constraint. Their embodiment is 1) distant, 2) environmental, 3) nearby, 4) full.		√ (1)
<b>Implementation</b>			
Pi1	The interface uses flexible and easily accessible sensor technologies.	*	√
Pi2	The interface is embedded.		$\chi$
Pi3	The interface uses constraints to simplify the detection of system states.		√
Pi4	Constraints define a limited number of finite states for the system.		√
Pi5	Tokens are tagged with unique IDs.		√
Pi6	The interface uses robust sensor technologies.		√
<b>Use (needing experimental validation)</b>			
Pu1	The interface reduces the need for visual attention.		
Pu2	The interface improves kinesthetic awareness.		
Pu3	The interface allows the externalization of the cognitive load.		

opposed to performative actions) in human cognition (pc3). As this is not the only possible explanation, we also included the externalization of the cognitive load in the properties to be tested (pu3).

Section 5 then analyzes the benefits and drawbacks of the T+C approach according to Bellotti et al.'s framework (*ibid.* section 5, p.106). The conceptual and technological responses provided by the original paper [1] to Bellotti et al.'s questions (“address”, “attention”, “action”, “alignment”, “accident”) [32] allow us to identify complementary properties (pc5 for “address”, pc6 and pi5 for “attention”). However, if a more complex result needs to be displayed, it is often done next to the T+C system, e.g., on a screen. This raises the issue of the distance between the place of action and the place of result display, common to TUI in general. We then propose to include a scale in the pc6 property expressing the distance between action and perception areas, based on Fishkin's “embodiment” scale [33]: 1) distant, 2) environmental, 3) nearby, 4) full.

Thanks to this analysis, we identified a heuristic grid of 24 core or optional items (Table 1) to guide the design of *token+constraint* systems. This work is a pragmatic and operational reformulation of the article [1].

## 4. Use cases

We illustrate the use of the heuristic grid defined in the previous section with two prototypes issued from the SLR: *PrimBox* [21] and *Tokens of Search* [25]. We selected these works since they are concrete applications of the T+C paradigm, which cite it explicitly (descriptive or generative level) and have been tested in real conditions with several participants. The results are shown in Table 1, and discussed below.



**Figure 1:** left) *PrimBox* prototype [21] (image source: [21]), right) *Tokens of Search* prototype [25] (image source: courtesy of the authors).

*PrimBox* ([21], **Figure 1** left) uses physical geometric shapes (pg1) that embody these artifacts in a virtual 3D environment (pg2). By placing a physical shape inside a box (pg3, pg5), it is added in the virtual environment (pg4). The user can then modify the properties of the shape by placing a card (position, size, color, rotation) on a RFID reader and manipulating sliders on the sides of the box [10]. The manipulation phase is not used (pg6), but could be considered to modify the position and rotation of 3D objects, rather than using sliders. The size and shape of the box do not allow identifying whether it is dedicated to 3D shapes instead of property cards (ps1), and whether it can accommodate one or more objects inside (ps2). All core properties are validated, allowing us to regard *PrimBox* as a T+C prototype. The heuristic grid also highlights usability issues and possible improvement through design guidelines, such as using manipulation phase to modify the 3D objects properties.

*Tokens of Search* ([25], **Figure 1** right) uses three kinds of objects (knot, rope and sticker) (pg1) to store URLs (pg2). The system also includes a wooden tray with a storage area and a circular RFID reader area (pg3). When an object is placed in the reader area (pg5), the URL associated to the object (pg4) is displayed on a touch screen [25]. The size of the constraint only allows one token at a time (ps2), as only one URL can be opened at the same time. All tokens are compatible with the constraint in terms of shape (ps1). The syntax of use is thus clearer than with *PrimBox*. The families taking part in the user study pointed out the lack of integration of the wooden tray in the house environment as a limitation (pi2). Users also had to develop strategies to separate tokens already associated with URLs from empty tokens. All core properties are validated, allowing us to regard *Tokens of Search* as a T+C prototype. Some design improvements can be identified from the heuristic grid analysis, for instance proposing additional containers for sorting the objects (pc3).

## 5. Discussion

The examples *PrimBox* and *Tokens of Search* show potential uses of the heuristic grid. The notion of core criteria helps assess if a prototype can be classified as T+C. As demonstrated above, both examples can both be regarded as T+C. The *general composition* properties (pg1..pg6) and *syntax properties* (ps1..ps3) allow characterization of prototypes according to the T+C paradigm in a standardized way. They also allow to compare the prototypes and their interaction syntax. For example, the interaction syntax of *Tokens of Search* is more explicit than the one of *PrimBox*, as the constraint's size allows only one token at a time. The *interaction properties* (pc1..pc6) assist reflecting about the uses and highlight prospective usability concerns. For example: affordance (pc5) and feedback (pc1, pc2), or distance between feedback and action areas (pc6). Not all properties “need” to be fulfilled, and some may even be contradictory (e.g., pc4: manipulation of several tokens at the same time and pc5: clear definition of the interaction zone). However, thinking explicitly about the most appropriate options allows informed design choices. The grid can also foster creativity: e.g., pc3 suggests using several untracked storage areas for the separation problem of *Tokens of Search*. This would match the example of the labeled plates of the Marble Answering Machine [34]. For *PrimBox*, pg6 could suggest using the manipulation phase to set the objects' position and orientation. *Implementation properties*, in turn, guide the implementation phase to foster reliability and flexibility of the prototype (e.g., using RFID instead of image processing, pi1). Finally, *use properties* require experimental validation. Their addition may encourage researchers/designers working on T+C prototypes to empirically experiment with them and thus increase the general knowledge on this paradigm and its properties.

We used Fishkin's taxonomy [33] to clarify the feedback embodiment in terms of distance between input and output (pc6, Table 1). This taxonomy has a second axis: the metaphor axis, ranging from “*no metaphor*” to “*complete metaphor*,” through the metaphors of “*noun*” (the form is similar to a real object), “*verb*” (the action is similar to an action in the real world) and “*noun and verb*” (the form and action are similar to those of a real-life object). The authors of the original T+C article [1] focused on abstract data without physical representations, so metaphors are weakly engaged in their examples. However, we note that many examples from the SLR use figurative tokens (geometric shapes, characters, stones, keys, etc.) and, less often, figurative constraints (doll's house, human-shaped puzzle). It might therefore be interesting to also cross-check the properties of our heuristic grid with this additional axis. Property pg2 on embodying data in tokens could potentially be related to the “*noun*” metaphor, and property pg4 on embodying actions in constraints with the “*verb*” metaphor. Even if it goes beyond the initial concept of *token+constraint*, this direction seems promising.

## 6. Conclusion

In this article, we examined the *token+constraint* paradigm [1]. To better understand the impact of the *T+C* paradigm in the realization and experimentation of published tangible prototypes between 2005 and 2020, we conducted a systematic review of the literature. The SLR indicated that, although the TOCHI article was widely cited, few prototypes can be regarded as T+C (30%). We also noted that it was complex to decide based on the initial article whether a prototype matches the initial paradigm or takes full advantage of its prospective benefits.

Thus, we proposed a heuristic grid of 24 properties divided into five categories, revisiting the original work, to investigate how the structural and functional nature of a prototype employing the *T+C* paradigm can best be characterized, and how one can measure the degree to which systems engage the proposed benefits for such paradigm. This grid supports description of prototypes according to a common T+C vocabulary, to assess their engagement with the concept, to compare prototypes, and to inform the design and development of *T+C* systems. The last part of the heuristic grid also encourages empirical experimentation of its theoretical benefits. We demonstrated this grid with two examples from the systematic literature review (*PrimBox*, *Tokens of Search*). We hope the reframing of the initial T+C paper [1] will enable others to design, develop and evaluate systems that engage the concept, and advance theoretical knowledge on this paradigm by supporting it with empirical work.

## 7. Acknowledgments

We would like to thank Mustapha Derras and Christophe Bortolaso for their collaboration on the PhD thesis funded by Berger-Levrault, and the authors of [25] for providing a photo of the prototype.

## 8. References

- [1] B. Ullmer, H. Ishii, et R. J. K. Jacob, « Token+constraint systems for tangible interaction with digital information », *ACM Transactions on Computer-Human Interaction*, vol. 12, n° 1, p. 81-118, mars 2005, doi: 10.1145/1057237.1057242.
- [2] D. Moher, A. Liberati, J. Tetzlaff, et D. G. Altman, « Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement », *International Journal of Surgery*, vol. 8, n° 5, p. 336-341, 2010, doi: 10.1016/j.ijssu.2010.02.007.
- [3] B. Ullmer et H. Ishii, « Emerging frameworks for tangible user interfaces », *IBM Systems Journal*, vol. 39, n° 3.4, 2000, doi: 10.1147/sj.393.0915.
- [4] E. H. Calvillo-Gómez, N. Leland, O. Shaer, et R. J. K. Jacob, « The TAC paradigm: Unified Conceptual Framework to Represent Tangible User Interfaces », in *Proceedings of the Latin American conference on Human-computer interaction - CLIHC '03*, 2003, p. 9-15. doi: 10.1145/944519.944521.
- [5] L. L. Scarlatos, « Tangible math », *Interactive Technology and Smart Education*, vol. 3, n° 4, p. 293-309, nov. 2006, doi: 10.1108/17415650680000069.
- [6] J. Marco, E. Cerezo, et S. Baldassarri, « ToyVision: a toolkit for prototyping tabletop tangible games », in *Proceedings of the 4th ACM SIGCHI symposium on Engineering interactive computing systems - EICS '12*, 2012, p. 71. doi: 10.1145/2305484.2305498.
- [7] E. Tobias, V. Maquil, et T. Latour, « TULIP: A widget-based software framework for tangible tabletop interfaces », in *EICS 2015 - Proceedings of the 2015 ACM SIGCHI Symposium on Engineering Interactive Computing Systems*, juin 2015, p. 216-221. doi: 10.1145/2774225.2775080.
- [8] M.-J. Hsieh, R.-H. Liang, D.-Y. Huang, J.-Y. Ke, et B.-Y. Chen, « RFIBricks: interactive building blocks based on RFID. », in *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI'18*, 2018, p. 1-10. doi: 10.1145/3173574.3173763.
- [9] H.-C. Kuo, R.-H. Liang, L.-F. Lin, et B.-Y. Chen, « GaussMarbles: Spherical Magnetic Tangibles for Interacting with Portable Physical Constraints », in *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 2016, p. 4228-4232. doi: 10.1145/2858036.2858559.
- [10] J. I. Winder et K. Larson, « Bits and Bricks. Tangible Interactive Matrix for Real-time Computation and 3D Projection Mapping », in *Future Technologies Conference*, 2017, p. 1113-1116.
- [11] B. Ullmer *et al.*, « Cartouche: conventions for tangibles bridging diverse interactive systems », in *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction - TEI '10*, 2010, p. 93. doi: 10.1145/1709886.1709904.
- [12] B. Ullmer *et al.*, « Casier: structures for composing tangibles and complementary interactors for use across diverse systems », in *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction - TEI '11*, 2011, p. 229. doi: 10.1145/1935701.1935746.
- [13] D. Schmidt *et al.*, « Kickables: tangibles for feet », *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, p. 3143-3152, 2014, doi: 10.1145/2556288.2557016.
- [14] A. G. de Siqueira, B. Ullmer, M. Delarosa, C. Branton, et M. K. Konkel, « Hard and Soft Tangibles: Mixing Multi-touch and Tangible Interaction in Scientific Poster Scenarios », in *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction - TEI '18*, 2018, p. 476-486. doi: 10.1145/3173225.3173252.
- [15] S. Follmer, D. Leithinger, A. Olwal, A. Hogge, et H. Ishii, « inFORM: dynamic physical affordances and constraints through shape and object actuation », in *Proceedings of the 26th annual ACM symposium on User interface software and technology - UIST '13*, oct. 2013, p. 417-426. doi: 10.1145/2501988.2502032.
- [16] L. Van Campenhout, J. Frens, C. Hummels, A. Staendert, et H. Peremans, « The enriching limitations of the physical world », *Personal and Ubiquitous Computing*, vol. 23, n° 1, p. 81-98, févr. 2019, doi: 10.1007/s00779-018-1176-8.
- [17] E. Jaffe, A. Dayan, et A. Dekel, « Cube management system: a tangible interface for monitoring large scale systems », in *Proceedings of the 2007 symposium on Computer human interaction for the management of information technology - CHIMIT '07*, 2007, p. 4. doi: 10.1145/1234772.1234778.
- [18] W. Maass et T. Kowatsch, « Let's Get Married: Adoption of Interactive Product Information For Bundle Purchases By Tangible User Interfaces », sept. 2009.
- [19] J. Zigelbaum, M. S. Horn, O. Shaer, et R. J. K. Jacob, « The tangible video editor: collaborative video editing with active tokens », in *Proceedings of the 1st international conference on Tangible and embedded interaction - TEI '07*, 2007, p. 43. doi: 10.1145/1226969.1226978.
- [20] J. I. Francesconi, M. L. Larrea, et C. Manresa-Yee, « Tangible music composer for children », *Journal of Computer Science and Technology*, vol. 13, n° 02, p. 84-90, oct. 2013.
- [21] G. Guerrero *et al.*, « Integrating Virtual Worlds with Tangible User Interfaces for Teaching Mathematics: A Pilot Study », *Sensors*, vol. 16, n° 11, p. 1775, oct. 2016, doi: 10.3390/s16111775.

- [22] S. Mora, I. Di Loreto, et M. Divitini, « The Interactive-Token Approach to Board Games », in *Ambient Intelligence. Aml 2015. Lecture Notes in Computer Science*, vol 9425, M. I. (eds) Ruyter B., Kameas A., Chatzimisios P., Éd. Springer, Cham, 2015, p. 138-154. doi: 10.1007/978-3-319-26005-1\_10.
- [23] T. Sapounidis, S. Demetriadis, et I. Stamelos, « Evaluating children performance with graphical and tangible robot programming tools », *Personal and Ubiquitous Computing*, vol. 19, n° 1, p. 225-237, janv. 2015, doi: 10.1007/s00779-014-0774-3.
- [24] N. Guo, « Melokey: Create Melody with Keys », in *Proceedings of the Audio Mostly 2016 - AM '16*, 2016, p. 234-239. doi: 10.1145/2986416.2986417.
- [25] J.-J. Lee, S. Lindley, S. Ylirisku, T. Regan, M. Nurminen, et G. Jacucci, « Domestic appropriations of tokens to the web », in *Proceedings of the 2014 conference on Designing interactive systems - DIS '14*, 2014, p. 53-62. doi: 10.1145/2598510.2598542.
- [26] E. S. Martinussen, J. Knutsen, et T. Arnall, « Bowl: token-based media for children », in *Proceedings of the 2007 conference on Designing for User eXperiences - DUX '07*, 2007, p. 3. doi: 10.1145/1389908.1389930.
- [27] M. Mosher, « If These Walls Could Speak: Tangible Memories », in *Proceedings of the 12th International Audio Mostly Conference on Augmented and Participatory Sound and Music Experiences - AM '17*, 2017, p. 1-4. doi: 10.1145/3123514.3123562.
- [28] D. Sellitsch et H. Tellioglu, « A Context Aware Music Player: A Tangible Approach », in *IUI 2014 Workshop: Interacting with Smart Object*, 2014, p. 56-59.
- [29] K. Detken, C. Martinez, et A. Schrader, « The search wall: tangible information searching for children in public libraries », in *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction - TEI '09*, 2009, p. 289. doi: 10.1145/1517664.1517724.
- [30] S. Rey *et al.*, « Build Your Own Hercules: Helping Visitors Personalize their Museum Experience », in *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction*, févr. 2020, p. 495-502. doi: 10.1145/3374920.3374978.
- [31] A. Girouard, O. Shaer, E. T. Solovey, G. M. Poor, et R. J. K. Jacob, « The Reality of Reality-Based Interaction: Understanding the Impact of a Framework as a Research Tool », *ACM Transactions on Computer-Human Interaction*, vol. 26, n° 5, p. 1-35, sept. 2019, doi: 10.1145/3319617.
- [32] V. Bellotti, M. Back, W. K. Edwards, R. E. Grinter, A. Henderson, et C. Lopes, « Making sense of sensing systems: Five Questions for Designers and Researchers », in *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '02*, 2002, p. 415. doi: 10.1145/503376.503450.
- [33] K. P. Fishkin, « A taxonomy for and analysis of tangible interfaces », doi: 10.1007/s00779-004-0297-4.
- [34] D. Bishop, « Marble answering machine », *Royal College of Art, Interaction Design*, 1992.
- [35] D. Schmidt *et al.*, « Kickables: tangibles for feet », in *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, 2014, p. 3143-3152. doi: 10.1145/2556288.2557016.

## A. APPENDICES

### A.1 Systematic Literature Review – references

Articles included in the SLR citing Ullmer et al. (2005): in English, featuring a tangible prototype, and published in a conference or peer-reviewed journal (only one article per set of duplicates). T+C indicates whether the tangible prototype implements at least one physical constraint (1: yes, 0: no).

ID	Reference	T+C?
4	Follmer, Sean, et al. "inFORM: dynamic physical affordances and constraints through shape and object actuation." <i>Uist</i> . Vol. 13. 2013.	1
7	Patten, James, and Hiroshi Ishii. "Mechanical constraints as computational constraints in tabletop tangible interfaces." <i>Proceedings of the SIGCHI conference on Human factors in computing systems</i> . ACM, 2007.	0
8	Fernaesus, Ylva, and Jakob Tholander. "Finding design qualities in a tangible programming space." <i>Proceedings of the SIGCHI conference on Human Factors in computing systems</i> . ACM, 2006.	0
11	Wakkary, Ron, and Marek Hatala. "Situated play in a tangible interface and adaptive audio museum guide." <i>Personal and Ubiquitous Computing</i> 11.3 (2007): 171-191.	0
15	Schiettecatte, Bert, and Jean Vanderdonck. "AudioCubes: a distributed cube tangible interface based on interaction range for sound design." <i>Proceedings of the 2nd international conference on Tangible and embedded interaction</i> . ACM, 2008.	0
17	Le Goc, Mathieu, et al. "Zoids: Building blocks for swarm user interfaces." <i>Proceedings of the 29th Annual Symposium on User Interface Software and Technology</i> . ACM, 2016.	0
19	Zigelbaum, Jamie, et al. "The tangible video editor: collaborative video editing with active tokens." <i>Proceedings of the 1st international conference on Tangible and embedded interaction</i> . ACM, 2007.	1
24	Valdes, Consuelo, et al. "Exploring the design space of gestural interaction with active tokens through user-defined gestures." <i>Proceedings of the SIGCHI Conference on Human Factors in Computing Systems</i> . ACM, 2014.	0
25	Sapounidis, Theodosios, Stavros Demetriadis, and Ioannis Stamelos. "Evaluating children performance with graphical and tangible robot programming tools." <i>Personal and Ubiquitous Computing</i> 19.1 (2015): 225-237.	1
27	Liang, Rong-Hao, et al. "GaussBits: magnetic tangible bits for portable and occlusion-free near-surface interactions." <i>Proceedings of the SIGCHI Conference on Human Factors in Computing Systems</i> . ACM, 2013.	0
28	Paelke, Volker, and Monika Sester. "Augmented paper maps: Exploring the design space of a mixed reality system." <i>ISPRS Journal of Photogrammetry and Remote Sensing</i> 65.3 (2010): 256-265.	0
34	Scarlatos, Lori L. "Tangible math." <i>Interactive Technology and Smart Education</i> 3.4 (2006): 293-309.	1
35	Marco, Javier, Eva Cerezo, and Sandra Baldassarri. "ToyVision: a toolkit for prototyping tabletop tangible games." <i>Proceedings of the 4th ACM SIGCHI symposium on Engineering interactive computing systems</i> . ACM, 2012.	1
37	Detken, Karen, Carlos Martinez, and Andreas Schrader. "The search wall: tangible information searching for children in public libraries." <i>Proceedings of the 3rd International Conference on Tangible and Embedded Interaction</i> . ACM, 2009.	1

ID	Reference	T+C?
38	Döring, Tanja, Axel Sylvester, and Albrecht Schmidt. "Exploring material-centered design concepts for tangible interaction." CHI'12 Extended Abstracts on Human Factors in Computing Systems. ACM, 2012.	0
39	Bonnard, Quentin, et al. "Paper interfaces for learning geometry." European Conference on Technology Enhanced Learning. Springer, Berlin, Heidelberg, 2012.	0
41	Schmidt, Dominik, et al. "Kickables: tangibles for feet." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2014.	1
42	Ullmer, Brygg, et al. "Cartouche: conventions for tangibles bridging diverse interactive systems." Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction. ACM, 2010.	1
44	Riedenklaue, Eckard, Thomas Hermann, and Helge Ritter. "An integrated multi-modal actuated tangible user interface for distributed collaborative planning." Proceedings of the Sixth International Conference on Tangible Embedded and Embodied Interaction. ACM, 2012.	0
45	Gurevich, Michael, Adnan Marquez-Borbon, and Paul Stapleton. "Playing with constraints: Stylistic variation with a simple electronic instrument." Computer Music Journal 36.1 (2012): 23-41.	0
47	Büschel, Wolfgang, et al. "T4-transparent and translucent tangibles on tabletops." Proceedings of the 2014 International Working Conference on Advanced Visual Interfaces. ACM, 2014.	0
48	Schoessler, Philipp, et al. "Kinetic blocks: Actuated constructive assembly for interaction and display." Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology. ACM, 2015.	0
54	Ullmer, Brygg, et al. "Casier: structures for composing tangibles and complementary interactors for use across diverse systems." Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction. ACM, 2011.	1
56	Bellucci, Andrea, et al. "Extreme Co-design: Prototyping with and by the User for Appropriation of Web-connected Tags." International Symposium on End User Development. Springer, Cham, 2015.	0
57	Dünser, Andreas, et al. "Evaluation of tangible user interfaces for desktop AR." 2010 International Symposium on Ubiquitous Virtual Reality. IEEE, 2010.	0
58	Yeh, Ron B., et al. "Interactive gigapixel prints: Large, paper-based interfaces for visual context and collaboration." Proc. Ubicomp. Vol. 6. 2006.	0
59	Coutrix, Céline, and Laurence Nigay. "Balancing physical and digital properties in mixed objects." Proceedings of the working conference on Advanced visual interfaces. ACM, 2008.	0
60	Tobias, Eric, Valérie Maquil, and Thibaud Latour. "TULIP: a widget-based software framework for tangible tabletop interfaces." Proceedings of the 7th ACM SIGCHI Symposium on Engineering Interactive Computing Systems. ACM, 2015.	1
61	Boussemart, Baptiste, and Sylvain Giroux. "Tangible user interfaces for cognitive assistance." 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07). Vol. 2. IEEE, 2007.	0
62	Le Goc, Mathieu, et al. "Smarttokens: Embedding motion and grip sensing in small tangible objects." Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology. ACM, 2015.	0

ID	Reference	T+C?
66	Jensen, Mads Vedel, and Marcelle Stienstra. "Making sense: Interactive sculptures as tangible design material." Proceedings of the 2007 conference on Designing pleasurable products and interfaces. ACM, 2007.	0
67	Maquil, Valérie. "Towards understanding the design space of tangible user interfaces for collaborative urban planning." Interacting with Computers 28.3 (2015): 332-351.	0
68	Lee, Jung-Joo, et al. "Domestic appropriations of tokens to the web." Proceedings of the 2014 conference on Designing interactive systems. ACM, 2014.	1
69	Fleck, Stéphanie, and Martin Hachet. "Making tangible the intangible: Hybridization of the real and the virtual to enhance learning of abstract phenomena." Frontiers in ICT 3 (2016): 30.	0
70	Martinussen, Einar Sneve, Jørn Knutsen, and Timo Arnall. "Bowl: token-based media for children." Proceedings of the 2007 conference on Designing for User eXperiences. ACM, 2007.	1
71	Lin, Chih-Lung, et al. "Emotion Caster: Tangible emotion sharing device and multimedia display platform for intuitive interactions." 2009 IEEE 13th International Symposium on Consumer Electronics. IEEE, 2009.	0
73	Miller, Chreston, et al. "Interaction techniques for the analysis of complex data on high-resolution displays." Proceedings of the 10th international conference on Multimodal interfaces. ACM, 2008.	0
75	Surie, Dipak, et al. "Egocentric interaction as a tool for designing ambient ecologies—The case of the easy ADL ecology." Pervasive and Mobile Computing 8.4 (2012): 597-613.	0
77	Guerrero, Graciela, et al. "Integrating virtual worlds with tangible user interfaces for teaching mathematics: A pilot study." Sensors 16.11 (2016): 1775.	1
79	Liang, Rong-Hao, Han-Chih Kuo, and Bing-Yu Chen. "GaussRFID: Reinventing physical toys using magnetic RFID development kits." Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. ACM, 2016.	0
81	Hsieh, Meng-Ju, et al. "RFIBricks: interactive building blocks based on RFID." Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. ACM, 2018.	1
82	Ward, Nicholas, and Giuseppe Torre. "Constraining Movement as a Basis for DMI Design and Performance." NIME. 2014.	0
83	De Raffaele, Clifford, Serengul Smith, and Orhan Gemikonakli. "The aptness of Tangible User Interfaces for explaining abstract computer network principles." 2016 IEEE Frontiers in Education Conference (FIE). IEEE, 2016.	0
84	Mora, Simone, Ines Di Loreto, and Monica Divitini. "The interactive-token approach to board games." European Conference on Ambient Intelligence. Springer, Cham, 2015.	1
91	Cheng, Lim Kok, et al. "GUI vs. TUI: engagement for children with no prior computing experience." Electronic Journal of Computer Science and Information Technology: eJCIST 3.1 (2011).	0
92	Couture, Nadine, Guillaume Rivière, and Patrick Reuter. "Tangible interaction in mixed reality systems." The Engineering of Mixed Reality Systems. Springer, London, 2010. 101-120.	0

ID	Reference	T+C?
93	Krause, Frank-lothar, et al. "Usability of hybrid, physical and virtual objects for basic manipulation tasks in virtual environments." 2007 IEEE Symposium on 3D User Interfaces. IEEE, 2007.	0
96	Maass, Wolfgang, and Tobias Kowatsch. "Let's get married: Adoption of interactive product information for bundle purchases by tangible user interfaces." (2009). 4th Mediterranean Conference on Information Systems (MCIS'09), Athens, Greece. pp 266-277.	1
98	Poor, G. Michael, et al. "Applying the Norman 1986 user-centered model to post-WIMP UIs: Theoretical predictions and empirical outcomes." ACM Transactions on Computer-Human Interaction (TOCHI) 23.5 (2016): 30.	0
99	Esteves, Augusto, and Ian Oakley. "Informing design by recording tangible interaction." CHI'11 Extended Abstracts on Human Factors in Computing Systems. ACM, 2011.	0
108	Jaffe, Elliot, Aviva Dayan, and Amnon Dekel. "Cube management system: a tangible interface for monitoring large scale systems." Proceedings of the 2007 symposium on Computer human interaction for the management of information technology. ACM, 2007.	1
111	Arif, Ahmed Sabbir, et al. "Extending the Design Space of Tangible Objects via Low-Resolution Edge Displays." Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction. ACM, 2017.	0
112	Christou, Georgios, Frank E. Ritter, and Robert JK Jacob. "Modeling prehensile actions for the evaluation of tangible user interfaces." ITI 2008-30th International Conference on Information Technology Interfaces. IEEE, 2008.	0
115	Coutrix, Céline, and Laurence Nigay. "An Integrating Framework for Mixed Systems." The Engineering of Mixed Reality Systems. Springer, London, 2010. 9-31.	0
163	Ehrenstrasser, Lisa, and Wolfgang Spreicer. "Personal Interaction through Individual Artifacts." Mensch & Computer 2012–Workshopband: interaktiv informiert–allgegenwärtig und allumfassend! (2012).	0
123	Jofre, Ana, Steve Szigeti, and Sara Diamond. "Citizen engagement through tangible data representation." Foro de Educación 14.20 (2016): 305-325.	0
124	D'Amico, Gianpaolo, et al. "Natural Human–Computer Interaction." Multimedia Interaction and Intelligent User Interfaces. Springer, London, 2010. 85-106.	0
126	Kuo, Han-Chih, et al. "GaussMarbles: spherical magnetic tangibles for interacting with portable physical constraints." Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. ACM, 2016.	1
128	Nakazawa, Jin, and Hideyuki Tokuda. "Phygital map: Accessing digital multimedia from physical map." 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07). Vol. 2. IEEE, 2007.	0
130	Appert, Caroline, et al. "Custom-made tangible interfaces with touchtokens." Proceedings of the 2018 International Conference on Advanced Visual Interfaces. ACM, 2018.	0
132	Celentano, Augusto, and Emmanuel Dubois. "Evaluating metaphor reification in tangible interfaces." Journal on Multimodal User Interfaces 9.3 (2015): 231-252.	0
134	Pathak, Akanksha, and Itsuo Kumazawa. "Usability evaluation of touch panel-based mobile device on user interface with multimodal feedback." IEEE-International	0

ID	Reference	T+C?
	Conference On Advances In Engineering, Science And Management (ICAESM-2012). IEEE, 2012.	
135	Francesconi, Juan Ignacio, Martín Leonardo Larrea, and Cristina Manresa-Yee. "Tangible music composer for children." <i>Journal of Computer Science and Technology</i> 13.02 (2013): 84-90.	1
140	Hansen, Thomas Riisgaard, Eva Eriksson, and Andreas Lykke-Olesen. "Movement and Space—Exploring the Space in Movement based Interaction." <i>The Workshop Call for Participation</i> . 2005.	0
142	Sánchez-Acevedo, Miguel A., Beatriz A. Sabino-Moxo, and José A. Márquez-Domínguez. "Mobile Augmented Reality: Evolving Human-Computer Interaction." <i>Mobile Platforms, Design, and Apps for Social Commerce</i> . IGI Global, 2017. 153-174.	0
144	Ventes, Christian C., et al. "A Programming Library for Creating Tangible User Interfaces." <i>GSTF Journal on Computing (JoC)</i> 4.1 (2018).	0
145	Le Goc, Mathieu, et al. "Dynamic composite data physicalization using wheeled micro-robots." <i>IEEE transactions on visualization and computer graphics</i> 25.1 (2019): 737-747.	0
149	de Siqueira, Alexandre G., et al. "Hard and Soft Tangibles: Mixing Multi-touch and Tangible Interaction in Scientific Poster Scenarios." <i>Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction</i> . ACM, 2018.	1
154	Huang, Yinghsiu, Kai-Wei Hsieh, and Huan-Nian Chen. "The Emotional Design by Combining Interactive Technologies and Imaginations." <i>Achten, Henri</i> (2012): 361-368.	0
161	Nofal, Eslam, et al. "Collaborative Tangible Gamification of Built Heritage for Young Museum Visitors." <i>Initial Training Network (ITN) on Digital Cultural Heritage (DCH) Final Conference on Digital Heritage</i> . 2017.	0
164	Bedwell, Ben, and Boriana Koleva. "Demonstrating Coherent Interactions between Personal Mobile Devices and Situated Installations." <i>Mobile Interaction with the Real World (MIRW 2007)</i> (2007): 47.	0
167	Panchaphongsaphak, Bundit, and Robert Riener. "Tokens and Board User Interface Based on a Force-Torque Sensing Technique." <i>2007 IEEE Symposium on 3D User Interfaces</i> . IEEE, 2007.	0
179	Sellitsch, David, and Hilda Tellioglu. "A Context Aware Music Player: A Tangible Approach." <i>on Interacting with Smart Objects</i> : 56.	1
181	Harlalka, Akash, et al. "Tangemon: A New TUI To Capture Precious Moments." <i>Proceedings of the India HCI 2014 Conference on Human Computer Interaction</i> . ACM, 2014.	0
185	Kobayashi, Shigeru, and Masayuki Akamatsu. "Spinner: A Haptic Reconfigurable Interface."	
188	Feng, Dan, et al. "Research on the tangible tabletop interaction system based on the optical sensors." <i>2011 International Conference on Optical Instruments and Technology: Optical Systems and Modern Optoelectronic Instruments</i> . Vol. 8197. International Society for Optics and Photonics, 2011.	0
190	Guo, Nathan. "Melokey: Create Melody with Keys." <i>Proceedings of the Audio Mostly 2016</i> . ACM, 2016.	1
205	Van Campenhout, Lukas, et al. "The enriching limitations of the physical world." <i>Personal and Ubiquitous Computing</i> 23.1 (2019): 81-98.	1

ID	Reference	T+C?
206	Winder, James Ira, and Kent Larson. "Bits and Bricks." Future Technologies Conference (FTC) 2017	1
207	WYSE, LONCE, and RODNEY BERRY. "The Music Table Revisited: Problems of Changing Levels of Detail and Abstraction in a Tangible Representation." Multimodal Studies. Routledge, 2012. 96-114.	0
210	Panchaphongsaphak, Bundit, Robert Riener, and Brygg Ullmer. "Contact-sensitive artefacts: implementing tangible interfaces through force-torque sensing." International Journal of Arts and Technology 1.3-4 (2008): 332-350.	0
212	Mosher, Matthew. "If These Walls Could Speak: Tangible Memories." Proceedings of the 12th International Audio Mostly Conference on Augmented and Participatory Sound and Music Experiences. ACM, 2017.	1
220	Maass, Wolfgang, et al. "Towards a transition to tangible commerce." 4th IEEE International Conference on Digital Ecosystems and Technologies. IEEE, 2010.	0
240	Bonillo, Clara, Javier Marco, and Eva Cerezo. "Developing pervasive games in interactive spaces: the JUGUEMOS toolkit." Multimedia Tools and Applications 78.22 (2019): 32261-32305.	0
241	DeLong, Sean, Ahmed Sabbir Arif, and Ali Mazalek. "Design and evaluation of graphical feedback on tangible interactions in a low-resolution edge display." Proceedings of the 8th ACM International Symposium on Pervasive Displays. 2019.	0
247	Xohua-Chacón, Antonio, et al. "Towards A Distributed Interactive Surface to Support Students with Hypoacusis in the Collaborative Learning of Relational Algebra." 2019 International Conference on Inclusive Technologies and Education (CONTIE). IEEE.	0
248	Rey, Stéphanie, et al. "Build Your Own Hercules: Helping Visitors Personalize their Museum Experience." Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction. 2020.	1
250	Veldhuis, Annemiek, Rong-Hao Liang, and Tilde Bekker. "CoDa: Collaborative Data Interpretation Through an Interactive Tangible Scatterplot." Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction. 2020.	0

## A.2 Classification of the T+C prototypes of the SLR

Classification of the 26 works citing the original work [1] and implementing at least one physical constraint. *Citation type* is based on the classification of Girouard et al. [31];

- “*cursory*” or superficial quote,
- “*descriptive*” describing the methodology or the arguments,
- “*term*” using the term as a usual word,
- “*supportive*” supporting a fact,
- “*justification*” supporting an argument,
- “*analysis*” evaluating the citing work,
- “*critique*” discussing limitations of the cited work,
- “*generative*” where the cited work inspires or informs the design of the citing work.

We used the color code from the original article by Girouard et al. to show the impacts within the cited articles (in blue for superficial citations, in green for low-level citations, in red for high-level citations).

*Field* is the field of application. *Users* indicates the target users. *Nb* indicates whether the system is multi (Mu), mono (Mo) or dual user (Du). *Test* indicates whether tests have been carried out in the laboratory (L) or in real

conditions (R) with at least one tangible constraint and for how many users at the same time. *Technology* indicates the technology used for token detection. *Stand-Alone/Integrated* indicates whether the T+C system is integrated into another technical device. *Data type* indicates whether the data is geometric/spatial or abstract. *A/M* indicates whether the prototype uses the association phase alone (A) or along with the manipulation phase (AM). *Nb C* indicates the number of constraints (n = several, NxT = number per token).

Article	Citation Type	Field	Users	Nb	Test	Technology	Stand-Alone /Integrated	Data type	A	M	Nb C
Generic technologies											
Follmer et al. 2013 [15]	Generative	Generic	All	Mu		Image processing	Integrated with shape-changing system	Various	A	M	n
Scarlatos 2006 [5]	Cursory	Scientific education	Child	Mu		Image processing	Stand-Alone	Geometric	A		n
Marco et al. 2012 [6]	Generative	Games	Child	Mu		Reactivision	Integrated on touch table	Various	A	M	n
Kuo et al. 2016 [9]	Generative	Games	All	Mo		Magnetism	Integrated with tablet computer	Spatial	A	M	n
Winder et Larson 2017 [10]	Critique	Generic	All	Mu		Image processing	Integrated (constructive assembly)	Spatial	A		n
Hsieh et al. 2018 [8]	Term	Games	All	Mu		Modified RFID	Integrated on touch table	Various	A		n
Tobias et al. 2015 [7]	Descriptive	Generic	All	Mu		Image processing	Integrated on touch table	Abstract (vote)	A		3
Ullmer et al. 2010 [11]	Justification	Generic	All	Mu		RFID, barcode, image processing	Integrated on touch table and tablet	Abstract	A	M	n
Ullmer et al. 2011 [12]	Critique	Generic	All	Mu		RFID, tag Surface	Integrated on touch table and tablet	Abstract	A	M	n
Siquiera et al. 2018 [14]	Term	Scientific poster	Student	Mu		Capacitive	Integrated on tactile Surface	Abstract	A	M	n
Schmidt et al. 2014 [35]	Generative	Generic	All	Mu		Pressure detection, FTIR	Integrated on video projected floor	Abstract	A	M	1

*Concrete use cases*

Article	Citation Type	Field	Users	Nb	Test	Technology	Stand-Alone /Integrated	Data type	A M	Nb C
Zigelbaum et al. 2007 [19]	Generative	Video editing	Adult	Mu	L, 2	Compaq Pocket PC	Integrated (constructive assembly)	Abstracts (video)	A	2,5 x10
Maas et al. 2009 [18]	Cursory	e-commerce	Adult	Du	L, 2	RFID	Stand-Alone	Spatial	A	5
Jaffe et al. 2007 [17]	Term	Supervision	Adult	Mu		LogoChip PIC OpenBoard	Stand-Alone	Abstracts (states)	A	3
Van Campenhouut et al. 2019 [16]	Cursory	Payment	Adult	Du	L,1		Integrated with screen and sliding system	Abstracts (money)	AM	1
Sapounidis et al. 2015 [23]	Generative	IT education	Child	Mu	R, 2	Connectors D9, D25 and MCU	Integrated (constructive assembly) + Lego robot	Abstracts (commands and parameters)	A	~3x20
Guerrero et al. 2016 [21]	Descriptive	Geometry education	Child	Mu	R, 2	RFID	Integrated with LCD screen	Geometric	A	1
Mora et al. 2015 [22]	Generative	Serious Game	Adult	Mu	L, 4	Sifteo Cubes	Integrated with printer, bar code reader	Spatial	A	n
Francesconi et al. 2013 [20]	Generative	Music education	Child	Mo		Image processing	Integrated with computer	Abstracts (music)	A	54
Lee et al. 2014 [25]	Generative	Sharing URL	Family	Mu	R, 5	RFID	Integrated with screen	Abstracts (URL)	A	1
Martinussen et al. 2007 [26]	Generative	Video playing	Child	Mo	R, 1	RFID	Integrated with television	Abstracts (video)	A	1
Sellitsch et Tellioglu. 2014 [28]	Term	Playing music	Adult	Mo	R, 1	NFC	Integrated with computer	Abstracts (music)	A	2
Guo. 2016 [24]	Generative	Music instrument	All	Mu		Image processing	Stand-Alone	Abstracts (music)	AM	4
Mosher. 2017 [27]	Generative	Audio diary	All	Mo		RFID	Stand-Alone	Abstracts (memories)	A	1
Detken et al. 2009 [29]	Term	Book search	Child	Du	R, 2	RFID	Integrated with tactile screen,	Abstracts (properties)	A	8

Article	Citation Type	Field	Users	Nb	Test	Technology	Stand-Alone /Integrated	Data type	A M	Nb C
							printer and phidgets			
Rey et al. 2020 [30]	Generative	Museum visit choice	All	Mu	L, 3	RFID	Integrated with tactile screen	Abstracts (characteristics)	A	5