Embodied Spatial Cognition in Tangible Computing

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CCS Concepts: •**Human-centered computing** → **Human computer interaction (HCI); Laboratory experiments;**

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1. LITERATURE REVIEW

Table I. Tangible interfaces for geospatial modeling: augmented architectural models

System	Interaction	GIS	User studies	Publications
Urp	Object detection		Case studies*	[Underkoffler and Ishii 1999]
				[Ishii et al. 2002]*
Collaborative Design Platform	Object detection			[Schubert et al. 2011]
	Touch			[Schubert et al. 2012]
	Sketching			[Schubert et al. 2014]
				[Schubert et al. 2015]

Table II. Tangible interfaces for geospatial modeling: actuated pin tables

System	Interaction	GIS	User studies	Publications
XenoVision Mark III Dynamic Sand Table	Sculpting			
Northrop Grumman Terrain Table	Sculpting			
Relief	Sculpting			[Leithinger and Ishii 2010]
				[Leithinger et al. 2009]
Recompose	Sculpting			[Leithinger et al. 2011]
	Gesture			[Blackshaw et al. 2011]
Tangible CityScape	Gesture			
Inform	Sculpting			[Follmer et al. 2013]
	Gesture			
	Object detection			

Table III. Tangible interfaces for geospatial modeling: augmented clay

System	Interaction	GIS	User studies	Publications
Illuminating Clay	Sculpting		Protocol analysis‡	[Piper et al. 2002a]
				[Piper et al. 2002b]
				[Fielding-piper 2002]
				[Shamonsky 2003]‡
				[Ishii et al. 2004]
				[Ratti et al. 2004]
Tangible Geospatial Modeling System	Sculpting	✓	Case studies*	[Mitasova et al. 2006]
				[Tateosian et al. 2010]*

Table IV. Tangible interfaces for geospatial modeling: augmented sandbox

System	Interaction	GIS	User studies	Publications
SandScape	Sculpting			[Ishii et al. 2004]
				[Ratti et al. 2004]
SandyStation	Sculpting			
Augmented Reality Sandbox	Sculpting			[Reed et al. 2014]
	Gesture			
Tangible Landscape	Sculpting	✓	Case studies*	[Petrasova et al. 2014]
	Object detection		User experiments†	[Petrasova et al. 2015]*
	Sketching			[Harmon et al. 2016b]†
The Augmented REality Sandtable (ARES)	Sculpting			[Amburn et al. 2015]
	Gesture			

2. APPENDIX

Table V. Tangible interfaces for geospatial modeling

System	Typology	Interaction	GIS	User studies	Publications
Urp	Augmented architectural models	Object detection		Case studies	[Underkoffler and Ishii 1999]
					[Ishii et al. 2002]
Illuminating Clay	Augmented clay	Sculpting		Case studies	[Piper et al. 2002a]
					[Piper et al. 2002b]
					[Fielding-piper 2002]
					[Ishii et al. 2004]
					[Ratti et al. 2004]
SandScape	Augmented sandbox	Sculpting			[Ishii et al. 2004]
					[Ratti et al. 2004]
XenoVision Mark III Dynamic Sand Table	Actuated pin table	Sculpting			
Northrop Grumman Terrain Table	Actuated pin table	Sculpting			
Tangible Geospatial Modeling System	Augmented clay	Sculpting	✓	Case studies	[Mitasova et al. 2006]
					[Tateosian et al. 2010]
Relief	Actuated pin table	Sculpting			[Leithinger and Ishii 2010]
					[Leithinger et al. 2009]
Recompose	Actuated pin table	Sculpting			[Leithinger et al. 2011]
		Gesture			[Blackshaw et al. 2011]
Collaborative Design Platform	Augmented architectural models	Object detection			[Schubert et al. 2012]
		Touch			[Schubert et al. 2011]
		Sketching			[Schubert et al. 2014]
					[Schubert et al. 2015]
Tangible CityScape	Actuated pin table	Gesture			
Inform	Actuated pin table	Sculpting			[Follmer et al. 2013]
		Gesture			
		Object detection			

Table VI. Tangible interfaces for geospatial modeling

System	Typology	Interaction	GIS	User studies	Publications
SandyStation	Augmented sandbox	Sculpting			
Augmented Reality Sandbox	Augmented sandbox	Sculpting			[Reed et al. 2014]
		Gesture			
Tangible Landscape	Augmented sandbox	Sculpting	✓	Case studies	[Petrasova et al. 2014]
		Object detection		User experiments	[Petrasova et al. 2015]
		Sketching			[Harmon et al. 2016b]
					[Harmon et al. 2016a]
The Augmented REality Sandtable (ARES)	Augmented sandbox	Sculpting			[Amburn et al. 2015]
		Gesture			

REFERENCES

Charles R Amburn, Nathan L Vey, Michael W Boyce, and Jerry R Mize. 2015. *The Augmented REality Sandtable (ARES)*. Technical Report October. US Army Research Laboratory. DOI:http://dx.doi.org/10.13140/RG.2.1.2685.0006

Matthew Blackshaw, Anthony DeVincenzi, David Lakatos, Daniel Leithinger, and Hiroshi Ishii. 2011. Recompose: direct and gestural interaction with an actuated surface. In *Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems - CHI EA '11*. ACM Press, Vancouver, 1237. DOI:http://dx.doi.org/10.1145/1979742.1979754

Benjamin Tarquinn Fielding-piper. 2002. *The Illuminated Design Environment : A 3-D Tangible Interface for Landscape Analysis*. Master's thesis. Massachusetts Institute of Technology.

Sean Follmer, Daniel Leithinger, Alex Olwal, Akimitsu Hogge, and H Ishii. 2013. inFORM: dynamic physical affordances and constraints through shape and object actuation.. In *UIST '13 Proceedings of the 26th annual ACM symposium on User interface software and technology*. ACM Press, St. Andrews, UK, 417–426. DOI:http://dx.doi.org/10.1145/2501988.2502032

Brendan A Harmon, Anna Petrasova, Vaclav Petras, and Helena Mitasova. 2016a. Computational Landscape Architecture: Procedural, Tangible, and Open Landscapes. In *Innovations in Landscape Architecture*, Jonathan R Anderson and Daniel Ortega (Eds.). Routledge. https://www.routledge.com/Innovations-in-Landscape-Architecture/Anderson-Ortega/p/book/9781138860681

Brendan A Harmon, Anna Petrasova, Vaclav Petras, Helena Mitasova, and Ross K Meentemeyer. 2016b. Tangible Landscape: cognitively grasping the flow of water. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. International Society of Photogrammetry and Remote Sensing, Prague.

H Ishii, C Ratti, B Piper, Y Wang, a Biderman, and E Ben-Joseph. 2004. Bringing Clay and Sand into Digital Design Continuous Tangible user Interfaces. {*BT*} *Technology Journal* 22, 4 (2004), 287–299. DOI:http://dx.doi.org/10.1023/B:BTTJ.0000047607.16164.16

H. Ishii, J. Underkoffler, D. Chak, B. Piper, E. Ben-Joseph, L. Yeung, and Z. Kanji. 2002. Augmented urban planning workbench: overlaying drawings, physical models and digital simulation. In *ISMAR '02 Proceedings of the 1st International Symposium on Mixed and Augmented Reality*. IEEE Computer Society, 203–211. DOI:http://dx.doi.org/10.1109/ISMAR.2002.1115090

Daniel Leithinger and Hiroshi Ishii. 2010. Relief: a scalable actuated shape display. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction - TEI '10*. ACM Press, Cambridge, MA, 221. DOI:http://dx.doi.org/10.1145/1709886.1709928

Daniel Leithinger, Adam Kumpf, and Hiroshi Ishii. 2009. Relief. (2009). http://tangible.media.mit.edu/project/relief/

Daniel Leithinger, David Lakatos, Anthony Devincenzi, Matthew Blackshaw, and Hiroshi Ishii. 2011. Direct and Gestural Interaction with Relief : A 2 . 5D Shape Display. *Proceedings of the 24th annual ACM symposium on User interface software and technology* (2011), 541–548. DOI:http://dx.doi.org/10.1145/2047196.2047268

Helena Mitasova, Lubos Mitas, Carlo Ratti, Hiroshi Ishii, Jason Alonso, and Russell S. Harmon. 2006. Real-time landscape model interaction using a tangible geospatial modeling environment. *IEEE Computer Graphics and Applications* 26, 4 (2006), 55–63. DOI:http://dx.doi.org/10.1109/MCG.2006.87

Anna Petrasova, Brendan Harmon, Vaclav Petras, and Helena Mitasova. 2015. *Tangible Modeling with Open Source GIS*. Springer.

Anna Petrasova, Brendan A Harmon, Vaclav Petras, and Helena Mitasova. 2014. GIS-based environmental modeling with tangible interaction and dynamic visualization. In *Proceedings of the 7th International Congress on Environmental Modelling and Software*, D.P. Ames and N. Quinn (Eds.). IEMSS. http://www.iemss.org/society/index.php/iemss-2014-proceedings

Ben Piper, Carlo Ratti, and Hiroshi Ishii. 2002a. Illuminating clay: a 3-D tangible interface for landscape analysis. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '02*. ACM Press, Minneapolis, 355. DOI:http://dx.doi.org/10.1145/503376.503439

Ben Piper, Carlo Ratti, and Hiroshi Ishii. 2002b. Illuminating Clay: A Tangible Interface with potential GRASS applications. In *Proceedings of the Open Source GIS - GRASS users conference 2002*. Trento, Italy.

Carlo Ratti, Yao Wang, Hiroshi Ishii, Ben Piper, Dennis Frenchman, John P Wilson, A Stewart Fotheringham, and Gary J Hunter. 2004. Tangible User Interfaces (TUIs): A Novel Paradigm for GIS. *Transactions in GIS* 8, 4 (2004), 407–421. DOI:http://dx.doi.org/10.1111/j.1467-9671.2004.00193.x

Sarah E. Reed, Oliver Kreylos, Sherry Hsi, Louise Kellogg, Geoffrey Schladow, Burak Yikilmaz, Heather Segale, Julie Silverman, Steven Yalowitz, and Elissa Sato. 2014. Shaping Watersheds Exhibit: An Interactive, Augmented Reality Sandbox for Advancing Earth Science Education. In *American Geophysical Union*.

Gerhard Schubert, Eva Artinger, Frank Petzold, and Gudrun Klinker. 2011. Bridging the Gap: A (Collaborative) design platform for early design stages. In *Education and Research in Computer Aided Architectural Design in Europe*, Vol. 29. Ljubljana, 187–193.

Gerhard Schubert, Eva Artinger, Violin Yanev, Frank Petzold, and Gudrun Klinker. 2012. 3D Virtuality Sketching: Interactive 3D-sketching based on real models in a virtual scene. *Proceedings of the 32nd Annual Conference of the Association for Computer Aided Design in Architecture* 32 (2012), 409–418.

Gerhard Schubert, David Schattel, Gudrun Klinker Marcus Tönnis, and Frank Petzold. 2015. Tangible Mixed Reality On-Site: Interactive Augmented Visualisations from Architectural Working Models in Urban Design. In *Computer-Aided Architectural Design Futures. The Next City - New Technologies and the Future of the Built Environment*. Vol. 527. Springer-Verlag Berlin Heidelberg, 55–74. DOI:http://dx.doi.org/10.1007/978-3-662-47386-3

Gerhard Schubert, Marcus Tönnis, Violin Yanev, Gudrun Klinker, and Frank Petzold. 2014. Dynamic 3d-sketching. *Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia* 19 (2014), 107–116.

Dorothy J Shamonsky. 2003. *Tactile, spatial interfaces for computer-aided design: superimposing physical media and computation*. Ph.D. Dissertation. Massachusetts Institute of Technology. http://hdl.handle.net/1721.1/67172

Laura Tateosian, Helena Mitasova, Brendan A Harmon, Brent Fogleman, Katherine Weaver, and Russell S Harmon. 2010. TanGeoMS: tangible geospatial modeling system. *IEEE transactions on visualization and computer graphics* 16, 6 (2010), 1605–12. DOI:http://dx.doi.org/10.1109/TVCG.2010.202

John Underkoffler and Hiroshi Ishii. 1999. Urp: a luminous-tangible workbench for urban planning and design. In *CHI '99 Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. ACM Press, New York, New York, USA, 386–393. DOI:http://dx.doi.org/10.1145/302979.303114