3D Motion Tracking in Architecture

Turning Movement into Form - Emerging Uses of a New Technology

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Tracking in space is an important bridge between physical and virtual environments. Optical 3D motion capture systems have become standards in the special effects industry and are increasingly common in medical applications, as well as in Virtual Reality (VR) and Augmented Reality (AR) set-ups. Beyond these applications, there are a number of emerging uses for such systems in architectural design. The possibility to track complex movements in space in real time and at high precision can open up new modes of interacting with spaces, and of generating movement as form as part of an architectural design process. What makes these possibilities particularly interesting for architectural investigations is that they don't have to be limited to a single user, but can happen in a collaborative way, involving many users simultaneously. After briefly explaining the technical aspects of the technology, an overview of such emerging uses is discussed. As an illustration of this potential, the results of a recent workshop are presented, in which a group of architecture students explored the hidden beauty of everyday movements and turned them into sculptural objects.

Keywords: *Motion Tracking; Animation; Design Process; Augmented Reality; Digital Fabrication*

Introduction

Optical 3D motion capture systems have become standard in the special effects industry and are increasingly common in medical applications, as well as in Virtual Reality (VR) and Augmented Reality (AR) set-ups. In this paper we propose that beyond these applications, commonly associated with 3D motion tracking systems, there are a number of emerging uses for such systems in architectural design. The possibility to track complex movements in space in real time and at high precision can open up new modes of *interacting with spaces*, and of *generating or analyzing movement as form* as part of an architectural design process. What's more, either process doesn't have to be limited to a single user, but can happen in a collaborative way, involving many users simultaneously.

After some technical background about motion tracking in general and the specific system used by the authors we will go on to discuss the feasibility and the potential of these uses. Furthermore we will illustrate some of this potential by describing a recent workshop in which the tracking system was used as part of an intense design charrette.

Background: Motion Tracking Technologies

Tracking in space is an important bridge between physical and virtual environments. Several technologies for tracking have been developed, including magnetic, mechanical, acoustic, inertial, optical and hybrid tracking (Bowman, 2004). Among these, optical tracking systems currently reach the highest level of precision. This explains their widespread use in character animation as well as in medical applications. In both fields, sub-millimeter accuracy is needed to achieve the level of nuance and detail that has become standard practice.

The biggest disadvantage of optical systems is the problem with occlusion that can only be countered with a high redundancy of cameras, leading to the other major disadvantage: the rather high cost of the hardware. Another problem is that in order to track well, the field of vision of the cameras should be free of glare and reflections, limiting the types of environments such set-ups can be used in. Nevertheless, today's state of the art systems are typically rather simple and hassle-free to set up and use. Besides speed and precision, their main advantage over most of the other mentioned technologies is that the user can be completely untethered from the computer, moving and behaving naturally (except for the markers they have to wear). This was the main reason for our decision to install an optical system at the no_Lab, the media laboratory of the institute of architecture and media (IAM) of TU Graz .

Technical Specifications

The system installed at IAM's no_Lab uses six cameras. Each camera is equipped with a strobe, a circular set of light emitting diodes (red or infra-red) around the lens. The system can track markers that are within the field of view of at least three cameras. Markers are reflective spheres attached to the body of the subject whose movement is to be recorded. The signals of the cameras are processed in dedicated hardware. The output of the system is a protocol of 3D coordinates that can be recorded or streamed for further processing. The size of the volume that can be tracked in the current setup is about 5 x 8 x 3 meters. Under optimal conditions up to 240 frames per second can be tracked. The number of individual markers that can be tracked can go up to about 200; groups of 5 such markers can be recognized as unique objects. As six cameras aren't sufficient for more complex applications we purchased a system that is compatible with that of a neighboring institute, which allows us to double the number of cameras for special purposes.

Potential areas of investigation in architecture

While applications in the mentioned industries (medicine, special effects, virtual and augmented reality) have driven the development of optical 3D tracking systems, their application is not limited to these. We see three distinct areas where such systems can enable new types of investigations that are relevant for architectural design:

1. form generation through movement and gestures,
2. spatial analysis
3. gestural interaction with spatial environments.

Form generation through movement and gestures

3D tracking technology can be used to make motion visible, to freeze its three-dimensional traces in time and to investigate them as form. Given how important the concept of motion is in the modern, 'space-time' discourse in architecture, the possibility to analyze movement as three dimensional form opens exciting new design potentials. This will be discussed in more detail in connection with the workshop which is described later on in this paper.

Spatial analysis: analyzing how people move and act in architectural spaces

Architects design the spatial confines people live and move in. So analyzing and studying the precise way in which people move in and through spaces gives valuable feedback about the way spaces are being used. It has been shown that tracking people's movements in public spaces can be a powerful way to assess their architectural qualities (Yan, 2005; Hillier, 1998). In the same spirit, but with much more detail than is usually available with the survey methods employed in the context of the space syntax research, optical tracking systems can be set up to record the movement patterns of people in buildings to enable new types of post-occupancy studies. While we have not undertaken any such study up to this point, they are certainly technically doable and they could provide insights and feedback unavailable with less accurate methods.

Interacting with spaces

Tracking systems can also be used as a new way to interact with spaces. By linking the tracking data in real time with functions and media installations of a room, buildings can react to their inhabitants' movements and behaviour, another way in which they can become sentient (Mahdavi, 2005). Our body's movements have extremely rich expressive powers. 3D motion tracking systems can give very detailed and nuanced analyses of our bodies' movements and could thus potentially tap into these expressive powers.

There was a shift in research on computer interaction towards a growing interest in physicality that recognized human beings as having a body, rather than just being "brains" and there are many investigations about what such gestural interfaces could potentially do (Camurri, 2004). They could for example be used to communicate with the technical systems of our surroundings in a more natural way than the current state of the art, the remote control. Moreover, it has been shown in the work of artists and researchers, that by means of tracking, space itself can become the interface: an invisible architecture (Novak, 2001).

Unlike with the remote control, if space is the interface, such interactions don't have to be limited to a single user. As mentioned above, the tracking system installed at our lab can track up to 200 separate markers. If five markers are combined in a particular way, they can become uniquely identifiable objects. Thus the system can simultaneously track up to 40 distinct objects in space. Of course this is a rather theoretical number, given the visibility problems that start to occur with more complex scenes. Still, not only can we communicate with a space by natural body movements, up to 40 people can theoretically do so at the same time.

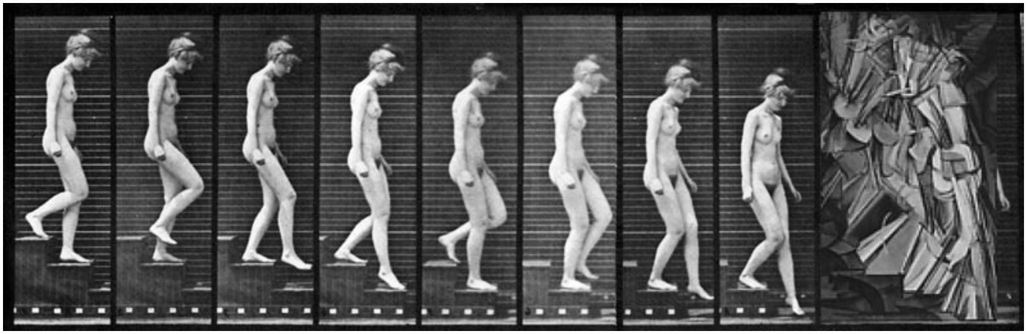


Figure 1
Technology influencing artistic expression: Marcel Duchamps' famous nude descending a stair was inspired by Eadweard Muybridge's photographs of bodies in motion.

Of course it is quite unclear if and how these possibilities will ever become more widespread in the way suggested here. The point we are making is simply that these are technical possibilities that are relevant for architecture and that they should be investigated further.

Workshop: sculpting motion

All of the possibilities mentioned in the last section would warrant more detailed discussion. In this paper we will only focus on the first of the three: the generation of form through movement.

The generation of form through movement was the focus of a recent workshop held at IAM. The workshop was held under the title 'Sculpting motion', referring to earlier work of two of the authors (Hirschberg, 2003) and a class with this title, taught at IAM. Rather than exploring synthetic motion, as in those earlier projects, the goal of the workshop was to create suspended wooden motion sculptures.

The workshop lasted for five days. Thus the task was rather ambitious and required a lot of intense work from the students. As is usually helpful in workshop situations with limited amounts of time, the goals and the technical means to reach them were clearly stated up front. The larger context of the task also involved reflecting about motion in art and architecture.

Motion in art and architecture

Motion has long been a central topic in art as well as in architecture. Particularly in the modern movement, theories about its importance and its expression were developed. Siegfried Giedion famously proclaimed a new conception of space, time and architecture which, according to him, had been brought about by the insights physicists had gained around the beginning of the 20th century (Giedion, 1984). Giedion quotes the Mathematician Minkowski as saying in 1908 that "From now on space alone and time alone are all but shadows and only the union of the two will save their existence". Following this argument, motion must be considered the essence of architecture.

The futurist movement in Italy, with artists such as Boccioni or Balla, was among the first trying to find an artistic expression of this new condition. But their work was not only a reaction to scientific theories as Giedion suggests. Just as Marcel Duchamps'

Figure 2
Students during motion capture sessions: the placement of the markers is a design decision.

famous nude descending a stair, their work clearly was inspired by the photographic motion studies of Eadwaerd Muybridge and others (Figure 1).

Thus a technological development, the high speed photography, which was later perfected by Harold Edgerton at MIT, triggered these influential artistic experiments. The photography of Muybridge opened up a new way to perceive and analyse motion (Solnit, 2003). In many ways, this can equally be said about today's 3D motion capture systems. We again find ourselves at a time when technology opens up an avenue of creative investigations unavailable up until now.

Among the first artistic fields to capitalize on this new technology was dance. There are practical reasons for this. Before motion capture systems came along, dance had neither a notational convention nor a recording technology general enough to record dances fully – a consequence of the complex movements in space dances consist of. The interest of dancers in the virtualization and thus preservation of their art is therefore not surprising. Artistic applications of motion tracking systems in dance, like in the work Paul Kaiser did with Merce Cunningham and others have already quite a tradition (Kaiser, 2002).

In architecture such applications are the rare exception. A fascination with motion and dynamic form can be found in the work of many contemporary architects. But projects that investigate the potential of using actual 3D tracking data in their design are far from common. The only exception the authors are aware of is the Ether/I project by the architecture group dECOI: a large sculpture which was developed based on tracking data from a dancing couple (Kolarevic 2003).

Generating form collaboratively

While artistic projects that have used motion capture technology typically deal with unusual types of motion, such as dance, there is hardly any work exploring normal everyday motion. One of the guidelines we gave the students at the outset was that they should develop scenarios with everyday types of motion – not only because we didn't have any dancers, but mainly because we felt that seeing motion as form was spectacular enough as such. Since part of what's interesting about the resulting sculptures is indeed whether one can detect what types of motions they originated from, using normal movements that anyone could perform made more sense. We also didn't want the students to become choreographers, but rather to reflect on the way their body moves in everyday situations.

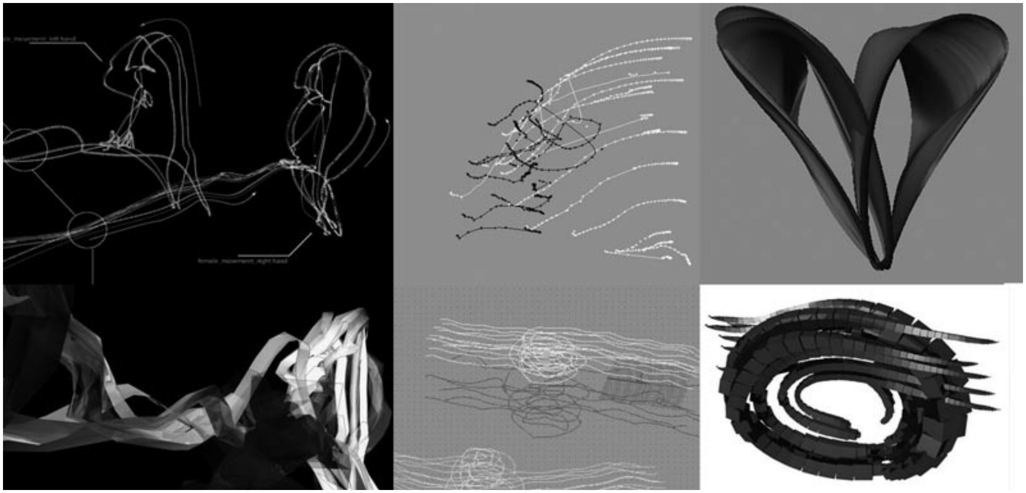
Collaboration was an important part of the entire workshop: students used a database driven website as their common environment for creative collaboration, which allowed them to exchange and be inspired by each other's work (Schmitt, 2001). Furthermore they worked on their sculptures in groups of two. Another rule for everyone was that the tracking setup wasn't an individual movement, but some social interaction between two or more persons. So not only did they work on their sculptures in groups, the very act of defining the spatial form was a collaborative act (Figure 2).

Despite these constraints, the movements students came up with varied greatly. One group threw a ball, one caught each other falling, one clapped their hands, one hugged, one helped each other getting up, etc. Along with the movement, the students also had to think about the placement of the markers. This is important, because in the end the paths registered for these markers were the only information they could develop their sculptures from.

Massaging the motion capture data

The step from having the tracking data to actually developing a sculptural form wasn't automatic, but one where students were to make design decisions about the type of object they would derive from their dataset. This step was worked on in the program MAYA. Most students applied their knowledge of MEL, the MAYA embedded scripting language to turn the data into a form according to some formal logic that would work well with the form. In most cases the data had to be

Figure 3
Massaging the motion capture data: students followed different procedures in turning the motion capture paths into digital models. Most made use of generative scripts to interpret the tracking data in an interesting way



simplified or trimmed. Many also went back to recording their action again with different marker positions.

For the massaging of the digital model, different strategies were explored: some turned the tracking points into individual objects, varying their size and/or rotation based on the speed of the movement (eg. the distance to the next object) thus creating a jagged, expressive look. Others lofted a surface along the tracking paths. They started developing a design-identity (Figure 3).

Suspended wooden sculptures

Every change of media has its own formal potential. We wanted the students to explore the specifics of each stage in the process rather than being too fixat-

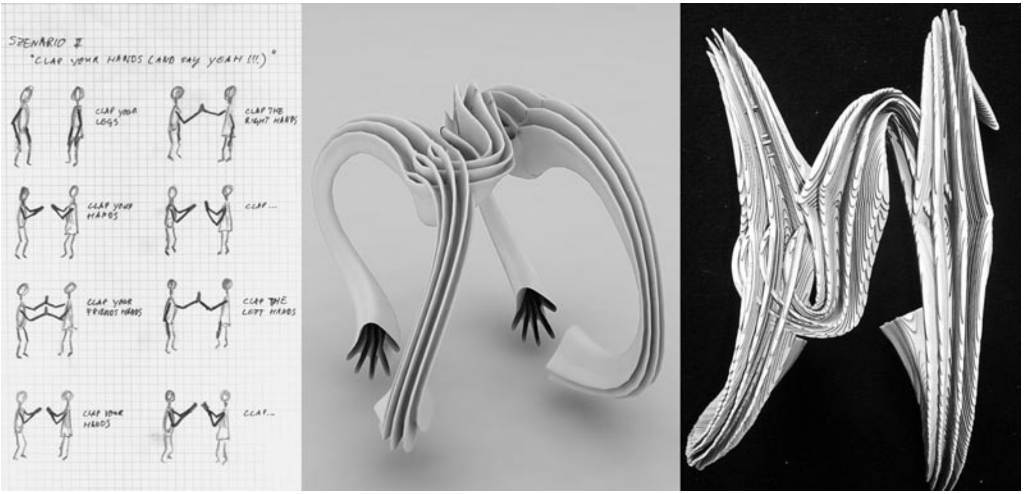


Figure 4
'Clap your hands', one of the most successful projects as initial sketch, as digital model and as digitally manufactured wooden sculptures

ed on the final result. While we had made it clear that their models would eventually have to be turned into a suspended wooden sculpture with the help of a laser cutter, the rendering of the digital model was supposed to be an object with its own integrity, not just an intermediate stage (Figure 4).

The step to turn the projects into physical sculptures was a great challenge. The students had to invent a construction logic that could be implemented using the laser cutter. But a lot of hands-on work was necessary despite the help of the machine (Figure 5).

At the end of the short but intense week, the wide array of sculptures the students presented made it clear that the concept of the workshop had indeed worked out very well. Many of the sculptures are both very interesting and beautiful to look at. One thing that many expressed is that "it's impossible to think up forms like that". So in a way, they are not designed. Yet they clearly are not random, either: one can feel that they were informed by a meaningful process, that they didn't just happen by chance. They are the results of an inquiry into the nature of motion, part experiment, part research, part design.

Conclusion

In this paper we described emerging uses of a motion capture technology for the field of architecture. We outlined three possible directions of architectural experimentation that can potentially be undertaken with such systems, but focused on only one in more detail: the generation of form through movement and gestures.

The results of the workshop presented to illustrate this approach shows that bringing our own bodies' movements into a form-making process can lead to rich and inspiring results. Turning movement into form can give unexpected insights into the intricate relationship between time and space – the very essence of what architects need to deal with.

So are workshops like the one described 'emerging uses' that could or should become more widespread? At this point this would be a bit of an overstatement. Before this or any of the other mentioned 3D motion tracking technologies can be employed more widely in the way proposed in this paper, considerable technical development must happen: the cost, the overhead of the set up or simply the distraction by the equipment will have to be minimized

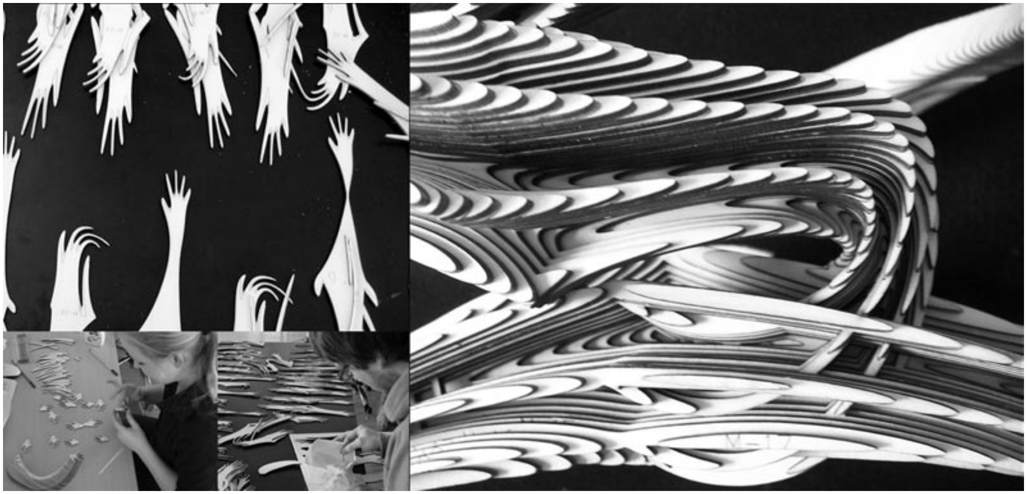


Figure 5
The coming together of the 'Clap your hands' wooden sculpture: "It's impossible to think up forms like that".

further. Nevertheless the degree of maturity current optical motion capture systems have reached in laboratory conditions makes them well suited for developing prototypical and experimental applications. While it may be too early to propose such applications for wider use, it is a good time to start exploring the future potential of motion tracking in architecture.

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References

Bowman, D. A., Kruijff E., LaViola J. JR., Poupyrev I. : 2004, 3D user interface design Theory and Practice, Addison Wesley, ISBN: 0201758679

Camurri, A., Mazzarino, B., Menocci, S., Rocca, E., Vallone, I. & Volpe, G.: 2004, Expressive Gesture and Multimodal Interactive Systems Proceedings of the AISB 2004 COST287-ConGAS Symposium on Gesture Interfaces for Multimedia Systems, The Society for the Study of Artificial Intelligence and the Simulation of Behaviour, 2004, pp 15-21.

Giedion, S.: 1984 (first ed. 1975), Raum, Zeit, Architektur Verlag fór Architektur Artemis Zórich und Mónchen. pp 284-286. (orig. ed. in English: Space time and architecture. first appeared in 1941)

Hillier, B.: 1998, "Space is the Machine" Cambridge University Press - 470p.

Hirschberg, U. and Sayegh, A.: 2003, Sculpting Motion, Exhibit in April 2003 at Gund Hall, Harvard Graduate School of Design, Cambridge, MA.

Kaiser P.: 2002. Frequently Pondered Questions, in Mitoma, Judy (ed.): Envisioning Dance on Film and Video, Routledge Press.

Kolarevic, B. (ed.): 2003. Architecture in the Digital Age: Design and Manufacturing, New York & London: Spon Press - Taylor & Francis Group.

Mahdavi, A.: 2005. Space Time, Mind: Towards an Architecture of Sentient Buildings in Martens, B. Brown, A.: Computer Aided Architectural Design Futures 2005, 301-310, 2005 Springer. Printed in the Netherlands.

Novak, M.: 2001, Invisible Architecture project at the 7th Venice biennale, mentioned in an interview with Alessandro Ludovico for neural.it April 2001 (http://www.neural.it/english/marcosnovak.htm) or in Jodidio, Philip: Architecture Now! 2. Taschen Verlag.

Schmitt, G.: 2001, Learning and Creative collaboration in Engeli, M. (ed.): Bits and Spaces: CAAD for Physiscal, Virtual and Hybrid Architecture at ETH Zurich, Birkhauser, Basel, Boston.

Solnit, R.: 2003, River of Shadows: Eadweard Muybridge and the Technological Wild West, Viking Adult

Yan, W., Kalay, Y.: 2005, Simulating Human Behaviour in Built Environments in Martens, B. Brown, A.: Computer Aided Architectural Design Futures 2005, pp. 301-310, Springer. Printed in the Netherlands.