Artif Life Robotics (2005) 9:165–174
DOI 10.1007/s10015-005-0350-z

PLENARY TALK

Henrik Hautop Lund · Thomas Klitbo · Carsten Jessen

Playware technology for physically activating play

Received and accepted: August 28, 2005

Abstract We present and use the robotic building block concept to create playware. Playware is the use of intelligent technology to create the kinds of leisure activity we normally label play, i.e., intelligent hard- and software that aims at producing play and playful experiences among users. The technological concept of physical building blocks with processing, input, and output (including communication) is derived from embodied artificial intelligence that emphasizes the role of interplay between morphology and control. We exemplify the building block concept with the tangible tiles that we created as components for a new kind of playground on which children can experience immediate feedback on their motions. Hence, this kind of playground allows the implementation of games and plays that demand physical activity amongst the users, and thereby contribute as a new tool in the fight against obesity. The tangible tiles are homogenous building blocks, which gives assembly, substitution, and production advantages. However, we may also create a system of heterogeneous building blocks, e.g., by adding special-purpose tiles such as loud-speaker tiles. We performed tests with the tangible tiles placed at a school for 2 months' continuous use.

Key words Playware · Building-blocks · Distributed control · Embodied artificial intelligence

H.H. Lund (✉)
Maersk Mc-Kinney Moller Institute for Production Technology, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark
Tel. +45-6550-3574; Fax +45-6550-7697
e-mail: hhl@mip.sdu.dk

T. Klitbo
Entertainment Robotics, Albani Torv 4, 5000 Odense C, Denmark

C. Jessen
Danish University of Education, Denmark

Introduction

We developed a novel building block technology for future playgrounds based upon principles from robotics and embodied artificial intelligence. We utilized the robotic building block concept in order to allow for easy physical reconfiguration of the playground – a building block concept derived from our focus on embodied artificial intelligence in which we state that the physical aspect of an entity (e.g., organism) plays a crucial role in defining the intelligence of that entity. We believe that there is an important interplay between the body and brain (i.e., between morphology and control) in intelligent systems, as verified with many biological and biorobotic investigations.[1–3] Therefore, when developing new technology for novel application areas, such as for future playgrounds, it is important to adopt a design principle that respects this body–brain interplay if one is designing for *flexible*, *adaptive*, and *intelligent systems*, as is the wish in many novel application areas. Often, flexibility should be in terms of both morphology and control of the system in the novel application area, and by designing for flexibility in both morphology and control, it is easier to achieve adaptive and intelligent systems, as found in the embodied artificial intelligence research. The reason is that the flexibility allows us, in an easy manner, to experiment with, and to find the right level and correspondence between, morphology and control in the system to be designed for the novel application area.

The embodied artificial intelligence approach puts emphasis on placing the robot/system in the real, physical environment and utilizing the characteristics of the real world in the development of the intelligent system. The resulting control systems provide a closed loop between environmental stimuli and actuation in the environment through the use of primitive behaviors executed in *parallel* and coordinated to provide the overall behavior of the system. So the overall behavior of the system becomes the *emergent effect* of the interaction with the environment and the coordination of the primitive behaviors. The task of the system designer becomes to design the correct primitive behaviors, and to

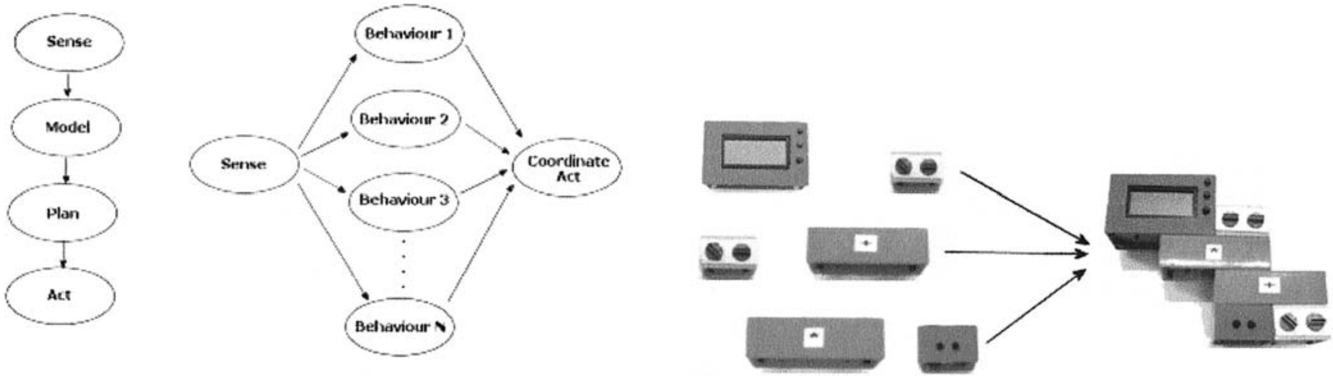

Fig. 1. *Left*. The classical AI approach to robot control with a sense–model–plan–act cycle vs. the modern AI approach to robot control with primitive behaviors running in parallel. *Right*. A graphical representation of the behavior block concept. Each building block represents both a *physical primitive* and a *functional primitive*, and when combined they will create an overall physical and functional structure. In more philosophical terms, the combination of the building blocks will create both the body and the brain

Fig. 2. Children playing phyzical games on the tangible tiles at an open square in the city of Odense, Denmark. Tangible tiles are building blocks placed both on the ground and on a wall

set up the primitive behaviors in the right manner to allow the desired overall behavior to emerge as the interplay between the primitive behaviors. With the same primitive behaviors, the designer may be given the opportunity to design many different overall behaviors of the system, depending on the designer's selection and set-up of the primitive behaviors.

For achieving such flexibility for systems acting in real-world applications, we developed a robotic building block concept. As a novel approach, we suggested expanding the more classical view on behavior-based systems[4] to include not only the coordination of primitive behaviors in terms of control units, but also the coordination of primitive behaviors in terms of physical control units. We can imagine a physical module being a primitive behavior. Thereby, the physical organisation of primitive behaviors will (together with the interaction with the environment) decide the overall behavior of the system. We term this the *behavior block concept*. In this concept, the overall behavior of a robotic artefact will emerge from the coordination of a number of physical building blocks that each represents a primitive behavior (Fig. 1, right).

In order to utilize this concept, it is necessary to have building blocks with certain properties. Each building block needs to have a physical expression, and should be able to process and communicate with its surrounding environment. The communication with the surrounding environment can be through communication to neighboring building blocks and/or through sensing or actuation.

We have applied this building block concept in numerous developments, especially for playware, and here, after a brief introduction to the field of playware, we will focus on the use of the building block concept for the development of future playgrounds with the aim of physically activating the population (Fig. 2).

Playware definition

We suggest the term "playware" as the use of intelligent technology to create the kinds of leisure activity we normally label play, i.e., intelligent hard- and software that aims at producing play and playful experiences among users, and of which, e.g., computer games are a subgenre. Further, we suggest the term "ambient playware" for playware with ambient intelligence characteristics. Ambient intelligence has been defined as the integration of technology into our environment, so that people can freely and interactively utilize it. In concrete terms, ambient intelligence is provided by a large number of small, intelligent devices, "in-built" into our surroundings. These devices have three important characteristics: they can be personalized, they are adaptive, and they are anticipatory.

It is our belief that such playware and ambient playware hold great potential for the development of future products and systems for entertainment. Playware can be directed toward indoor or outdoor use, on small scale or large scale, etc. Here we will focus on the use of playware on a large scale for an outdoor scenario, namely for the creation of future playgrounds. Here, the playware can be directly focused on creating new spaces and possibilities for physical activating play, and thereby promote physical health, and thus contribute to the reduction of health problems such as obesity and other lifestyle-related diseases which are of increasing concern in all industrialized societies. In contrast to the vast majority of research into childhood, health, and media, we believe that at least part of these problems in industrialized societies should be dealt with not by fighting electronic and digital media and play equipment, but by releasing their potentials. Playware that can initiate physical play should, of course, not be seen as the only or the ultimate solution, but we regard the concept as hugely important for society to prevent the growing obesity threat.[5]

Playware technology

In order to support playware and the play environment, it is vital to design and develop units that can be distributed in the environment that the users inhabit (e.g., playgrounds, school yards, city squares, skateboard ramps, sports centres). The units to be developed can be considered as *building blocks* with processing and communication capabilities. These units are placed in the real, physical environment and utilize the characteristics of the real world to emerge as a collective, intelligent "robotic" system.

According to this building block concept, we developed a set of tangible tiles for physically activating children in their play. The tangible tiles are initially utilized in 2D on the ground, but are also extended with wireless hand-held units in order to develop activities where children can interact with virtual and/or physical elements in 3D. Wireless technologies have great potential for the development of new products within the genre of play and games, but exploitation of that potential requires the development of an easily accessible technical platform that joins the technologies together and makes the products widely usable for both producers and users. We believe that wireless technology should be incorporated in building blocks in the long term, but we started by making the wired playware building blocks described below. However, these can easily be mounted on both ground and walls in order to create activity in 3D, e.g., as shown in Fig. 2.

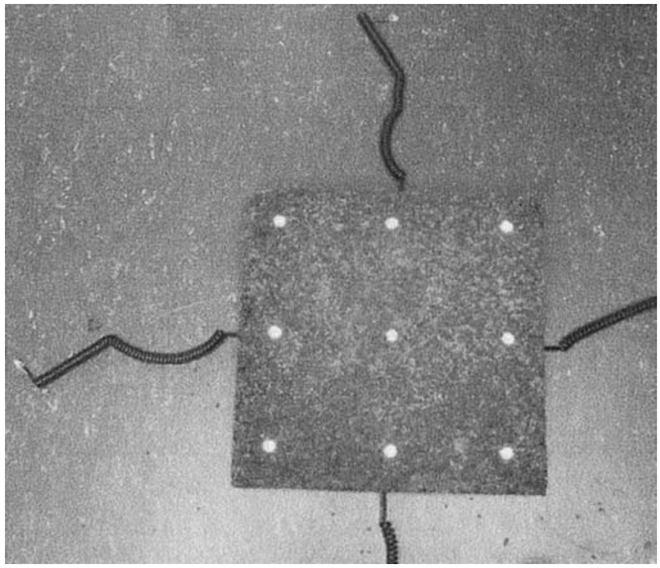

Fig. 3. First prototype of the tangible tiles. It has 3×3 LEDs and wired communication to its neighbors

The *tangible tiles* are new play elements which function as building blocks by containing processing power, sensors, actuators, and communication capabilities. We made two prototype iterations of the tangible tiles. In the first implementation, the tangible tiles have a soft surface, and each measures 40 cm × 40 cm. Inside each tile there is a force-sensitive resistor (FSR) that can register when someone jumps on the tile. In the first prototype, the actuation consists of 9 red LEDs and 9 blue LEDs distributed equally on the tile in a 3×3 matrix (Fig. 3). Furthermore, on the back of the tile there is room for a microcontroller (ATmega128) that can register activity from the sensor and control all the 18 LEDS individually. With this simple tile, it is possible, e.g., to switch from blue to red or from red to blue every time someone jumps on the tile.

The second version is a smaller building block measuring 21 cm × 21 cm, and the actuation consists of one light that can have 8 different colors, achieved by controlling and combining the output from 4 RGB colored LEDs placed next to each other. The color of each LED is PWM-controlled from the ATmega128. Further, in the second version, sound can be controlled as output from the tiles. The second version of the tile is made out of rubber. The rubber connectors of a tile are made so that each side matches another side on another tile (see the tile design in Fig. 4). However, it is possible to connect tiles on a half or a quarter the length of a neighboring tile. There is a small raised circular platform on top of the rubber tiles, under which the FSR sensor is placed.

Inside each rubber tile is a plastic sandwich that measures 17 cm × 17 cm × 1.9 cm, which contains the electronics and has holes for the LEDs, the FSR sensor, and the communication cables (Fig. 5). 5V power and communication is transferred through the cables. The electronics consist of an

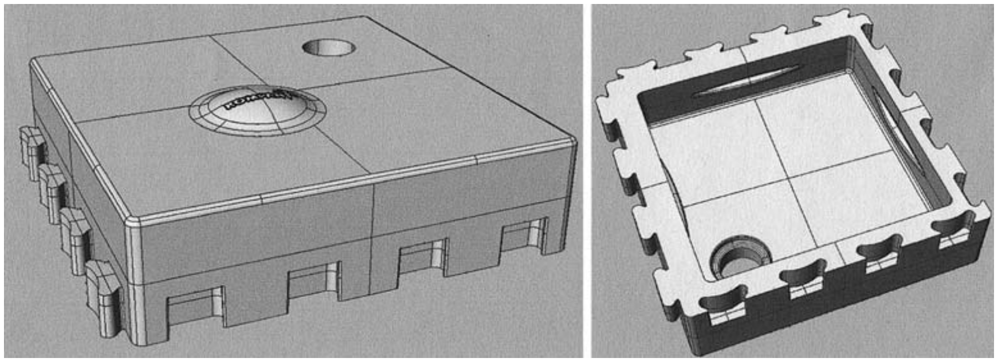

Fig. 4. Second prototype of the tangible tiles

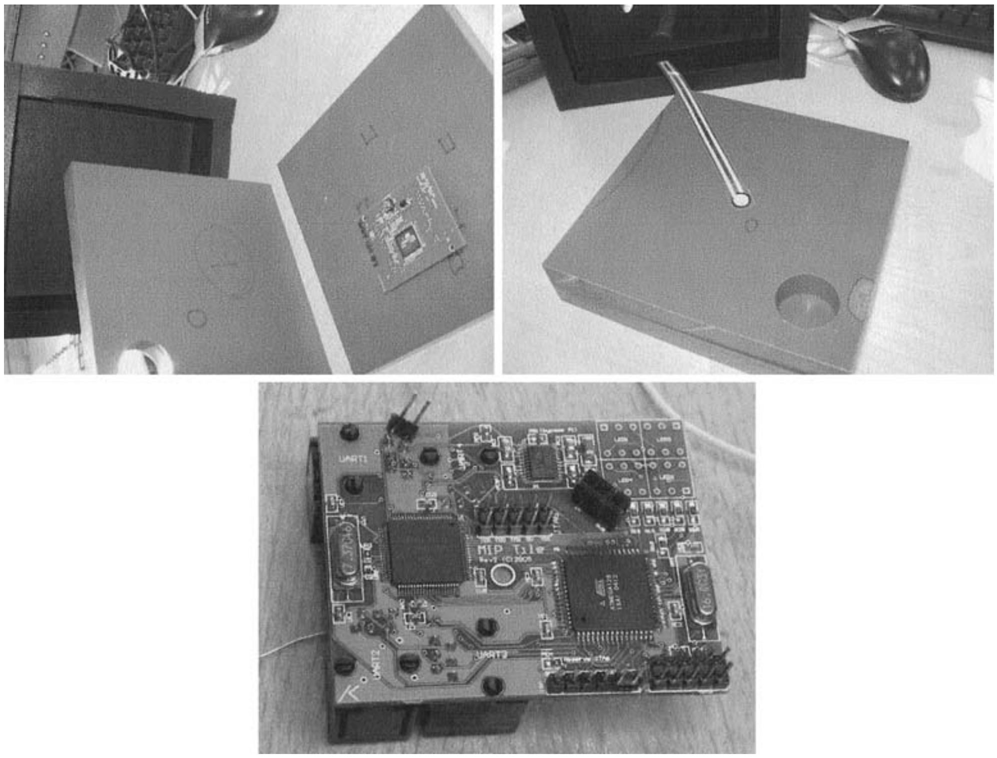

Fig. 5. The hardware of the tangible tiles with the ATmega128 microcontroller

ATmega128 microcontroller with a 16-MHz crystal, and a Texas Instrument TL16C754B Quad UART with 64-byte FIFO for the communication channels. The microprocessor can be programmed in AVR-gcc. The communication between the tiles ensures that it is possible to do more complex games than just switching colors on a single tile. The microcontroller in each tile can be used to communicate with the four neighboring tiles, and it can also control the games. Since they are building blocks, there is distributed processing, and this gives the possibility of using different physical configurations (e.g., different numbers of tiles and different placements) without having to change any program. Each tile can check if it has a neighbor on each of its four sides.

The tiles can be viewed as the technological platform that provides us with opportunities for creating new kinds of play and games. It is possible to have more than one game in the microcontroller and make different physical configurations of the tiles so the users can play different types of games. Hence the tangible tiles are an example of playware, and if implementations make them adaptive, personalized, and anticipatory, we would view them as an example of ambient playware. The attribute of being distributed building blocks for playware provides a higher degree of flexibility than in a centralized approach, but also puts demands on the architecture – it may, for instance, need to include protocols for communication and provide means for recognizing the physical connectivity of building blocks.

The playware architecture is a layered division between hardware, protocols, and applications (Fig. 6). Future developments of this architecture may include a higher-level operating system layer between the protocol layer and the application layer. In general, this architecture development should allow interested parties in playware to work on different layers, e.g., hardware developers for the hardware

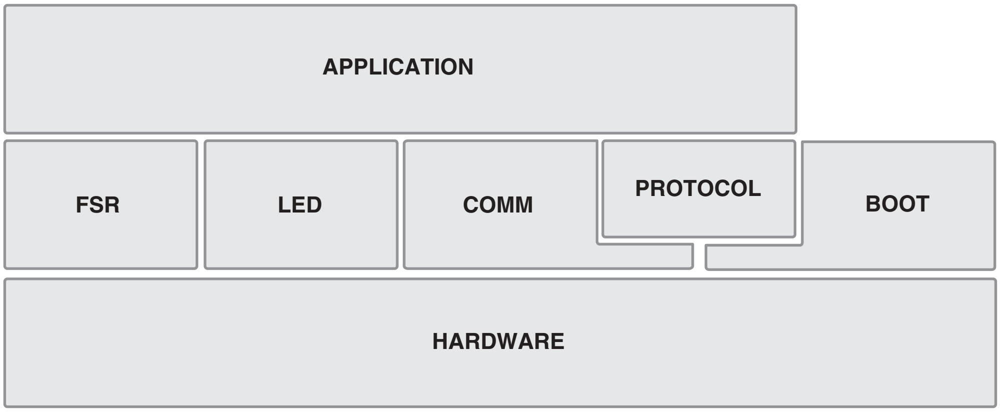

Fig. 6. A starting point for the development of playware architecture

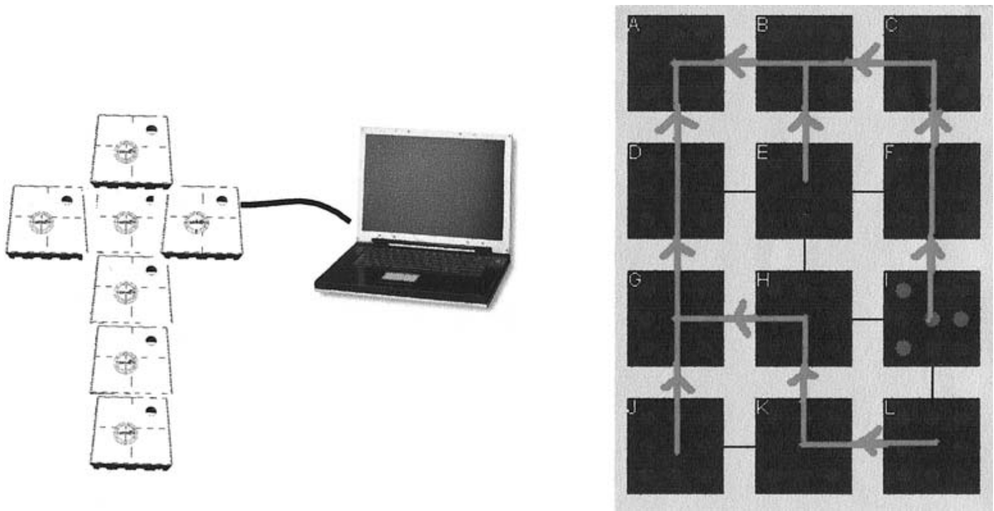

Fig. 7. The root starts by telling all its neighbors to become children in the tree structure. Then these new children ask all their neighbors whether they are part of the tree structure (do they have a parent?). If not, the tile asking will become their parent in the tree structure. This continues until all tiles have a parent, and the structure will depend on which neighbor asks first to become parent

level, OS companies for operating system level, and game developing companies for the application level.

It should be noted that we provide a boot loader which allows the programming of one tile (building block), which thereafter spreads the program to its neighbors, which in their turn spread it to their neighbors, etc. – a process which allows the application programmer to program just one tile (e.g., by inserting a disk, CD-ROM, USB-key, or similar in future). At the same time, the boot loader makes a map of the tree structure of the physical configuration of the tiles. Thereafter, the system is aware of the neighborhood topology, and any building block (tile) can communicate with any other building block in the structure (if necessary by going through the root building block; Fig. 7, right, in which A is the root building block). Whether such communication is needed may depend on the application. Indeed, in a fully distributed system, the application designer may often choose to use local communication (e.g., the Pong game described below), or a mix between local and global communication.

By making playware technology based upon the building block concept, we provide freedom to explore the creative potential of the play designers, the playground installation workers, and the end-users. The system can be put into different physical configurations and different input/output configurations in a very easy manner by putting building blocks together. The behavior of the system may then depend on the physical arrangement (the morphology), the uploaded program (the control), and the interaction by the users (the environment). As shown in Fig. 8, the tiles can be put into different physical arrangements and different games may be uploaded to the structure through a master tile (or similar). In these examples, the user may have configured and uploaded games for playing hopscotch, ping-pong, or the color race.

The two different prototype systems of the tiles can be viewed as working with the building block concept with different *granularity*. In the case of the first prototype, each building block is physically large (40 cm × 40 cm) and provides numerous outputs (3 × 3 light spots). The second prototype is smaller, both physically (21 cm × 21 cm) and in terms of output (1 light spot). On the other hand, the input is "smaller" in the first prototype (1 bit digital 0/1 input) and "larger" in the second prototype (8 bit analog 0–255 input).

We believe that, in general, for creating the right playware technology for a given application, it is important

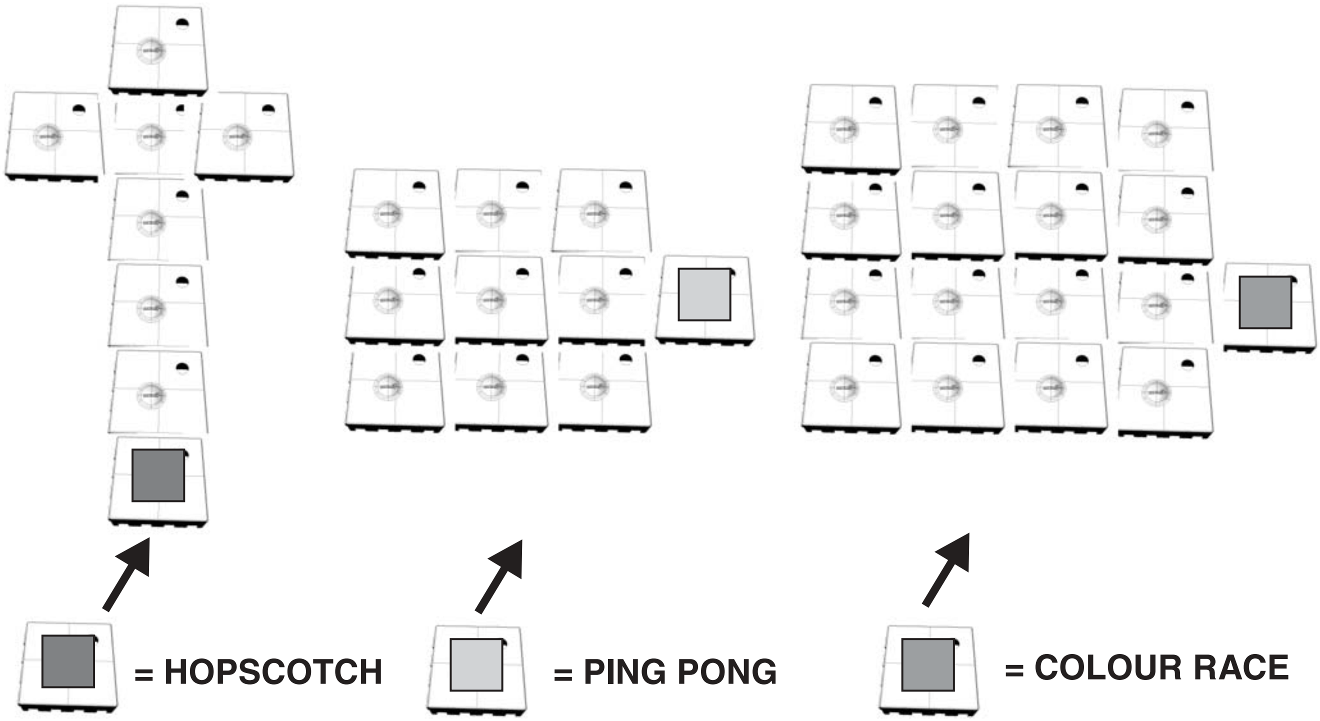

Fig. 8. Different games can be made by adding a particular tile for each game

Fig. 9. *Left*. School pupils from the Danish school Tingager Skolen interacting with the first prototype system during the 2-month test. *Right*. Kindergarten children in a color race game on the second prototype system

to design with the granularity of the building blocks in mind, both in terms of physical granularity (e.g., size, input, output) and control granularity (behavioral complexity of a single building block). In the example of the tangible tiles, we went from a system composed of fewer, larger building blocks to a system with higher granularity composed of more, smaller building blocks, in order to provide further freedom in the physical configuration of the overall system. For achieving the same output pattern of the overall system, we need to utilize more building blocks with the second prototype system, but the higher granularity allows us to construct physical arrangements that are not possible with the first prototype system.

Playware technology evaluation

We implemented different games on the tangible tiles and analyzed children's physical play on the tiles in continuous use for 2 months at a school in Denmark (Tingager Skolen, Denmark) (e.g., Fig. 9). In one of the games, the *color race*, children compete against each other (more children can play in groups) by first choosing a color (either blue or red) and then jumping quickly on the tiles so that they turn into their color. Another example is a tangible version of the computer game *Pong*, where a red arrow moves around randomly and when it gets to one side of the tiles configuration, a child has to step on the tile quickly in order to return the arrow to the opponent. The arrow can move to one of the connected neighbors. Finally, on top of the first prototype system, we also implemented the "wicked witch game." The wicked witch game is an extension which uses PDAs and WiFi localization to provide story lines and guidance for the children's play in order to encourage them to take physical activity, e.g., by running to the tiles, and play different games on the tiles. The second prototype allowed us to implement a version of the color race in which up to six different colors are present at one time, and a specific sound is associated with each color so that the sound is played when a child jumps on the tile that lights up in the associated color. In this version of the color race, it is easier for more children to play together at the same time, and it is also easier to make performance activities. The implementation of the color race and the ping-pong game on the tiles is made as described below.

Color race

The system recognizes the structure of all the tiles. It then randomly chooses six of these tiles, and a different color is placed on each chosen tile. When a player steps on, e.g., the tile with the yellow color, the system randomly finds a new tile that is not occupied by another light and moves the yellow light accordingly. At the same time the system plays the "yellow sound" and increases the yellow score by one. When a specific color has been stepped enough times and reaches a score of ten, that color has won the game. All the tiles will then show a light of the winning color and play the winning color sound. Afterwards, six new tiles are chosen and the color race starts again.

Ping-pong

The ping-pong game can have distributed control between the tiles without the need of a master. The tiles will all have the same program, and their behavior depends on where they have neighbors. Imagine having several tiles placed in a rectangle. Player one is placed on the north side and player two on the south side. When power is connected to the system we need a red "ball" on just one of the tiles. We choose this to be the north-west tile. If the tiles are placed in a rectangle, only one tile will have neighbors on the south and east but no neighbors on the north and west, making it the north-west tile. This tile will light up red and will head south. When a tile has to pass the red ball it can go either west, east, or straight ahead. It checks in which of these directions it has neighbors, and then chooses one of these randomly to pass the ball on to, e.g., if our ball is on the north-west tile and is heading south, it can choose to pass the ball to either its east neighbor or its south neighbor. This way the ball will wander around randomly, but will never go backwards. When a ball heading south reaches a tile with no south neighbors, it knows it has reached the side of player two. Now player two has to step on this tile quickly otherwise player two will loose the game and the ball will start to flash before a new game starts. If player two steps on the tile in time it will change direction and start heading north. Furthermore, every time a player hits the ball it will start move faster from tile to tile, making it more and more difficult for the players to hit the ball. All the tiles have the same program but use different functions depending on their neighbors. A tile without a north or south neighbor has to check if a player steps on the tile and also change the direction of the ball. A tile with both a north and a south tile only has to pass the ball on with the necessary speed and desired direction. Therefore, a tile also communicates the current speed and direction when telling a neighbor to receive a ball.

Random function

In both ping-pong and the color race we use a random function to make choices. AVR-gcc has a built-in random function that needs a seed to generate random numbers. To make sure we do not have the same game every time we turn off the power and then turn it on again, we can use human interaction to decide the seed value. A counter is running all the time in the microprocessor, and when a human steps on a tile we take the current value of the counter and use it as the seed for the random function.

During the continuous use of the first prototype tiles in the school for 2 months, we were permitted to set up a web camera to record the activity on the tiles. It was observed that even if the boys were most active, girls were present in 38% of the activities. There were no differences in gender in the preference for the two games, ping-pong and the color race. Most of the time the children were playing by themselves (37%) or with one other child (32%). In 14% of instances three children were playing together, and in 17% four or more children were playing together. It was observed that the children mostly competed against each other, but also instructed each other how to play/compete. Also, some teenage children used the tiles as a pastime while talking on their mobile phones.

Homogeneous vs. heterogeneous building blocks

Here we have exemplified the robotic building block concept for large-scale, outdoor playware. However, this is a general approach that can be used both in creating other kinds of playware, and in other intelligent artefact designs. For playware, we have utilized the building-block concept on a smaller scale with the design of I-Blocks[6,7] and African I-Blocks,[8] and for self-reconfigurable robots[9] we utilized a similar building-block concept for the design of ATRON modules (Fig. 10).

When creating artefacts such as the playgrounds, manipulative and therapeutic toys, and shape-shifting systems with the robotic building-block concept, distributed processing in physical building blocks gives us a natural flexibility and redundancy that may allow the end-user or

Fig. 10. Examples of the robotic building-block concept in the design of different systems. *Left*. I-Blocks used by Italian schoolchildren to support developing emotional knowledge. *Center*. African I-Blocks used by a child at Ilembula Hospital in a rural area of Tanzania for therapy. *Right*. ATRON modules used to create shape-shifting robots

the system itself to rearrange and recreate. We believe that it is important to provide system designers and end-users with the freedom to create their own system by providing them with the appropriate building blocks; appropriate in terms of both physical and behavioral aspects, or in other words, in terms of both body and brain.

Indeed, in order to support playware and play environments, it is vital to design and develop units that can be distributed in the environment that the users inhabit, e.g., playgrounds, school yards, city squares, skateboard ramps, and sports arenas. Hence, in future we believe it to be important to provide building blocks with wireless communication, easy attachment, and low energy use in order to allow end-users to distribute such building blocks anywhere in their daily environment where they would like to create a play space, and even to be able to create and disassemble ad-hoc play spaces within seconds or minutes.

An important aspect to consider when utilizing the building-block concept is whether to design and use homogenous or heterogeneous building blocks. In our case, the tangible tiles are homogenous building blocks, which has the advantage that:

- attachment to other units is always the same;
- a faulty unit can easily be substituted;
- the production cost is low.

However, these advantages come with the price that no extra hardware functionality can easily be added. All hardware functionality should be included in all the homogeneous building blocks, whereas the heterogeneous approach allows the construction of just one building block with a particular hardware. This may be advantageous if many different input/output functions are needed.

In our design of other building-block systems, a similar consideration has taken place. For the ATRON system we also designed homogeneous building blocks, since we wanted to facilitate attachment, self-repair, and production. On the other hand, the I-BLOCKS and African I-BLOCKS were designed as heterogeneous systems, since we needed to allow the end-users to create with many input and output possibilities. For the tangible tiles, we have in fact investigated the expansion to a heterogeneous system by constructing a sound tile. In this case, the connection mechanism is similar to that of the other tiles, and it is simply adding a loud speaker system to the tiles hardware, as illustrated in Fig. 11.

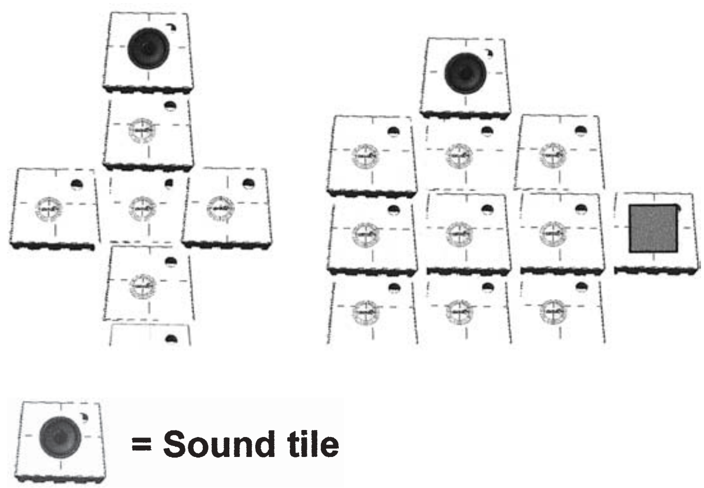

Fig. 11. The tangible tiles as a heterogeneous building block system. We constructed a new sound tile that differs from the other tiles

Centralized vs. distributed control

The ping-pong game exemplified the *distributed* nature of processing in the tangible tiles, but interestingly, the use of our robotic building-block concept for the playware playgrounds came from a longer design process started in 2001, in which we initially investigated a *centralized* approach to creating physical play activity amongst children. We created a playground, as shown in Fig. 12, with touch sensors and loud speakers in different positions on the playground. A PLC (Fig. 12, right) would control the output from a speaker to play somewhere on the playground, and the child was supposed to run, jump, or crawl as fast as possible to that position to press a code on the touch sensor at that position. By making a sequence of such loud speaker and touch events, we could create different paths on the playground that the children should pass through as quickly as

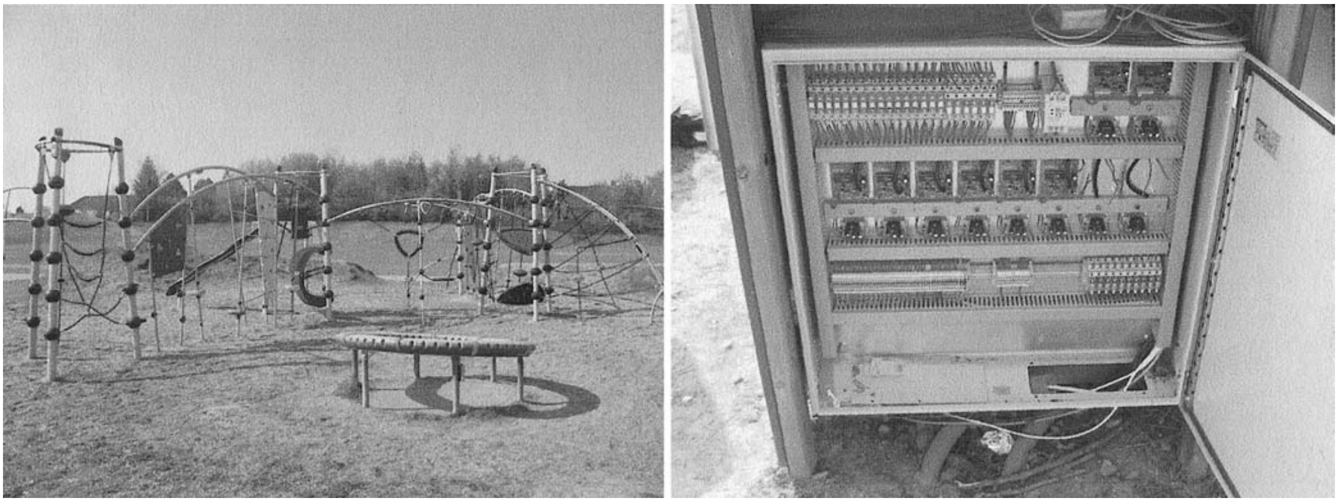

Fig. 12. The very first playground with touch sensors and loudspeakers controlled by PLC

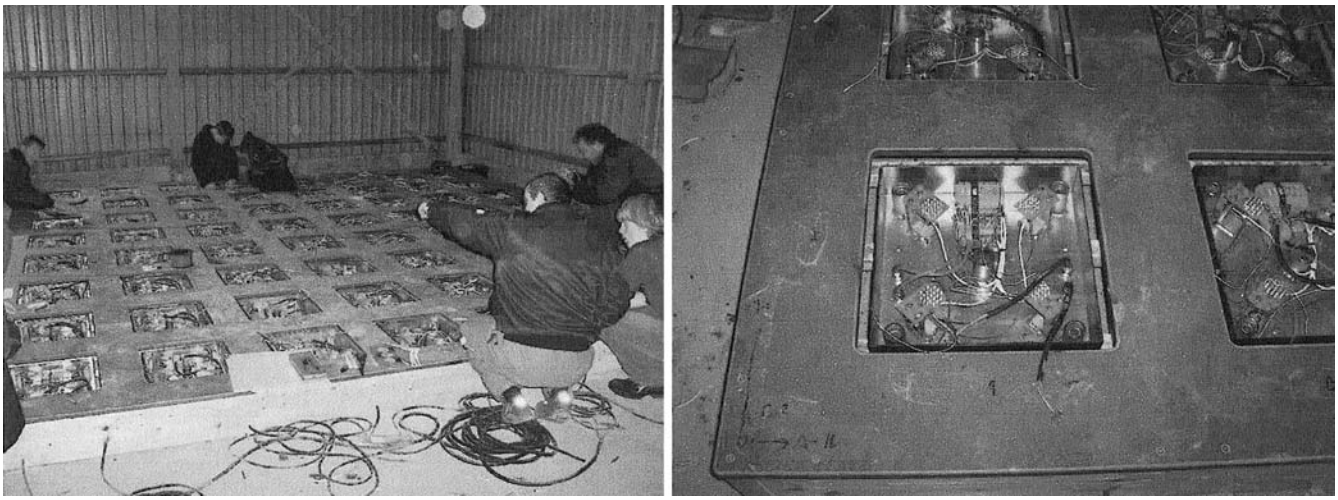

Fig. 13. Construction of the PLC-controlled system of 8×8 tiles, which is now part of the event park Danfoss Universe in Denmark

possible. The playground was set up at the Sdr. Nærå school in Denmark for a few months. However, we observed that the play became a very sequential activity, where the children needed to wait for their turn to run through the virtual path on the playground. This meant that the playground was soon used by only a few children. Hereafter, a long analysis, evaluation, and design process led us to the use of the robotic building-block concept in the subsequent design phase, since this concept would provide a distributed system on which we could imagine several things happening in parallel, and not only sequentially as with the centralized approach. Also, the distributed nature of the building-block concept would allow those installing the playgrounds to make different configurations in a very easy manner. Even end-users could start manipulating the physical set-up of the play space when using the building-block concept. Hence, this distributed building-block concept also seemed more open-ended than the centralized approach.

Of course, a PLC system can be used to emulate a distributed system such as the tangible tiles, even though the ease of substitution and the creative aspects of morphology will get lost. So it will never be a real distributed building-blocks system as intended in this paper. Anyway, the event park Danfoss Universe in Denmark used our work to create a PLC-controlled system of 8×8 tiles as part of their event park which opened in May 2005 (Fig. 13).

Discussion and future work

Some other researchers have worked on developing building blocks, such as the z-tiles,[10] mainly as input devices. Here, we put emphasis on a building-block concept derived from robotics, which demands both input and output. In related research, researchers have mainly looked at devices to obtain input to control a centralised music/dance performance, or for surveillance purposes. Also, the characteristics of having building blocks with sensing, processing, actuation, and communication capabilities should allow us to develop the physical play in interaction with units that can *adapt* and *learn*. Therefore, ambient playware development aims at creating an ambient intelligence environment for physical play by investigating different issues from modern artificial intelligence such as adaptability and learning, and applies them to physical interactions in the interaction space. For instance, adaptation and learning may be utilized for the system to reconfigure processing (e.g., games) based on the physical rearrangement of building blocks performed by the user in the interaction space. In the longer term, the ambient intelligence solutions should be developed at different scales, from objects to environments, and be able to sustain various human activities. These solutions are based on intelligent building blocks that allow non-expert users to develop intelligent interactive artefacts and environments. Also, modern artificial intelligence may be used to allow the playware to learn about interaction patterns, and adapt the play to challenge users at different levels, and thereby create personalization of the playware. Our ongoing work with the use of multi-agent systems techniques and neural network training indicates that we can classify the behavior of children in different age groups with very high accuracy.

For obtaining more freedom in the physical construction with building blocks, we expect wireless communication to play a crucial role in future playware technology. Already we have investigated combining PDAs with WiFi communication with the tangible tiles, and used the Ekahau system to localize the PDA, which would be a story teller for the user. However, in future wireless technology should play an even more prominent role in the playware technology by replacing the wired connection between the building blocks. This should allow end-users to place playware building blocks in any space that they would like to transform to a play space, e.g., playgrounds, school yards, city squares, skateboard ramps, or sports centres. Then, a crucial field of research becomes how to power all the independent building blocks, which may not all be physically connected.

Conclusion

We have presented the building-block concept for creating playware technology. The concept arises from embodied artificial intelligence that highlights the interplay between morphology and control in intelligence. Hence, for the creation of intelligent artefacts such as playware, we find it important to allow easy access to both morphology manipulation and control manipulation for the playware designer (e.g., game designer, playground installation worker, or teacher) in order to allow the playware designer to find the right morphology-control set-up in the creation of an *intelligent* playware system.

At the same time, the building-block concept gives immediate production advantages, in that it becomes possible to mass-produce, while at the same time allow a potentially huge range of products from a single production. This is because the building blocks can be configured in any physical set-up that an end-user may wish (the lower freedom limit being defined by the building block granularity). In the case of playgrounds, a school may want a large rectangular playground in the school yard, whereas a city may want a triangular playground in a park, and a small cubic playground on a city square. The playground installation worker can easily make the three different installations by combining the mass-produced building blocks to give the desired configurations. Further, the architecture presented here provides an automatic way for the system to recognize its own configuration, and together with the boot loader, this makes it is easy for the installation worker, the teacher, or the child to upload new games to the whole system.

Acknowledgments Some of the hardware and software implementation work was done by A. Derakhshan, F. Hammer, and J. Nielsen, and the design by C. Isaksen from Isaksen Design. C. Balslev, Nielsen, performed user studies and analyses. KOMPAN, Mads Clausen Institute, and Danfoss Universe participated in Body Games development.

References

1. Lund HH, Webb B, Hallam J (1998) Physical and temporal scaling considerations in a robot model of cricket calling song preference. Artif Life 4:95–107
2. Pfeifer R, Scheier C (1999) Understanding intelligence. MIT Press, Cambridge
3. Peremans H, Müller R (2005) The CIRCE biomimetic bat head. Proc Inst Acoustics, in press
4. Brooks RA (1986) A robust layered control system for a mobile robot. IEEE J Robotics Automat 2:14–23
5. Lund HH, Jessen C (2005) Playware: intelligent technology for children's play. Technical Report TR-2005-1, June, Maersk Institute, University of Southern Denmark. http://www.mip.sdu.dk/research/technical-reports/2005/ (checked 28-08-2005)
6. Lund HH, Marti P (2005) Designing manipulative technologies for children with different abilities. Artif Life Robotics 9:175–187
7. Nielsen J, Lund HH (2003) Spiking neural building block robot with Hebbian learning. Proceedings of the IEEE International Conference on Intelligent Robots and Systems (IROS2003), IEEE Press, pp 1363–1369
8. Lund HH, Vesisenaho M (2004) I-blocks in an African context. Proceedings of the 9th International Symposium on Artificial Life and Robotics (AROB'9), Oita, ISAROB, pp I-7–I-12
9. Lund HH, Beck R, Dalgaard L (2005) ATRON hardware modules for self-reconfigurable robotics. Proceedings of the 10th International Symposium on Artificial Life and Robotics (AROB'10), Oita, ISAROB
10. Richardson B, Leydon K, Fernström M, et al. (2004) Z-tiles: building blocks for modular, pressure-sensing floorspaces. Proceedings of CHI 2004, ACM, pp 1529–1532