Bridging the gap between real and virtual objects for tabletop games

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***Abstract*— In this paper, we present a collaborative tabletop game which combines both the real and virtual world. The main motivation for this game was to augment a traditional board game with additional digital content. Users have to work together and place domino pieces in each level. We present the implementation including the hardware components and the software implementation, describe the game design, and discuss the game. Finally, we also conclude with the results of our first pilot study providing some design guidelines for similar game setups.**

***Index Terms*— Tabletop game, physical objects, digital pen, design.**

I. INTRODUCTION

Over the last decade we recognize a shift in the game industry: the rendering quality and the performance of console games are getting better and better. On the other side, the industry is also looking forward to find new ways for attracting more people to play games. Nintendo's wii controller, for instance, allows a very intuitive interaction. Consequently, people have more fun and they have more experience with the system [8]. However, people are rather focused on the interaction with the system than having a better interpersonal communication (see Fig. **1**).

Fig. 1: Desktop-based games are often an isolated activity – even when gamers play in a multi-player mode. Therefore, traditional board games are still very popular.

On the other side, people still love to play with traditional board games, such as Risk, Monopoly, and Trivial Pursuit. Both video and board games have their strengths and the logical consequence is to merge both worlds.

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Fig. 2: Comino is a tabletop game and combines both worlds.

Tabletop games are providing an ideal interface for digital board games. In contrast to desktop based games, people have the advantage to play and to see each other. They can collaborate better and have more fun during the game. Especially, when talking about role-based games, tabletop setups can become very interesting since they provide a great face-to-face communication.

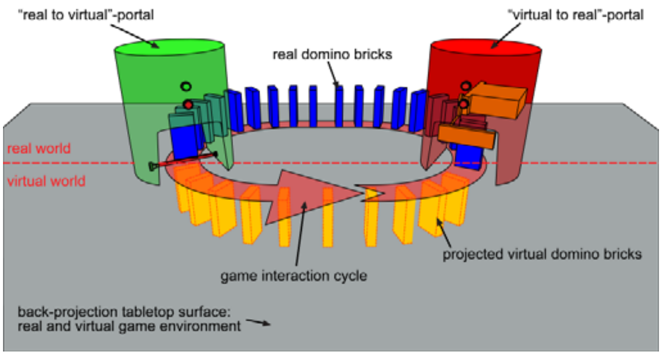


Fig. 3: Physical portals help to close the gap between the real and virtual domino pieces.

In this paper, we present the tabletop game Comino, which closes the gap between traditional board games and computer based games. Motivated by the traditional Dominoes and by the Incredible Machine, we wanted to create a game, which allows children to solve a puzzle by using real and digital domino pieces. Fig. **2** shows a snapshot of our tabletop game. The real pieces can push the virtual and vice versa. Thus, users have to find out, in which situation they have to use the real pieces and where the performance of the digital pieces can support them solving a task. Fig. **3** depicts both the real and digital world.

Both worlds are connected through the portals, which allow a seamless integration of the digital domino pieces in the real environment.

II. RELATED WORK

Multimodal interfaces that combine gestures with additional modalities like speech have been examined since the early 80s and have shown significant potential to make human-computer interaction in games more natural and efficient. A number of systems have emerged in recent years in which users can interact by speech combined with pointing or more complex gestures. Using a variety of available sensors and targeting diverse use environments, existing research has addressed the recognition of detailed hand gestures as well as full body (pose) gestures [7]. Physical user action as an interaction modality have been recently explored in research projects, mostly in an entertainment/sports context [21], and has entered the commercial realm with the EyeToys extension for the Sony Playstation 2 and with the Nintendo wii console. Emerging platforms like Microsoft's Surface table [12] also provide future game developers with exiting new hardware.

In the same way, Mixed Reality and Pervasive Games are increasingly getting popular. Human Pacman [4] and ARQuake [25] are just two examples, where the researchers integrated traditional console games in a Mixed Reality environment. Both games are outdoor MR games and setups users have to wear a head mounted display (HMD) and a GPS-based tracking device. In contrast to these games, our focus was in improving traditional board games (e.g. Risk, Monopoly) with digital content.

In order to improve the social gaming experience, Magerkurth et al. propose a tabletop setup which combines the advantages of a digital environment with the social impact of board games. The game combines a wall and a digital display. Users play with their personal devices and with the public displays, and the communication can be done through headsets (for personal communication) and loudspeakers (public communication). Moreover, users are sitting face-to-face, they share the same experience, and they play in a new digital/real world [17]. Most of recent work on interactive surfaces deals with merging real with the virtual (digital) enabling people to share the same experience [6][20]. Barakonyi et al. present in [2] the game MonkeyBridge and extend the idea of Magerkurth. They implemented a collaborative Augmented Reality game employing autonomous animated agents. Although playing around a table, the authors implemented their game using HMDs. Again users can use real objects, which have to be placed correctly, to guide digital, augmented avatars.

Wilson demonstrated PlayAnywhere, a flexible and transportable tabletop projection setup [27] and PlayTogether, an interactive tabletop system that enables multiple remotely and co-located people engaging in games with real games pieces [28]. Moreover, Wilson also presented a car racing game at the ACM SIGGRAPH course "Interaction Tomorrow" in 2007 in which he tracks the table's surface. In combination with a physics engine, the racing cars are moving on the surface realistically. To facilitate the design of tabletop applications, guidelines have been introduced by Scott et al. [22]. Köffel et al. introduce a set of ten heuristics for the development of tabletop games [14]. In the following sections, we are presenting some selected related work from the field of tabletop games in more detail.

A. KnightMage

KnightMage[17] is based on the STARS-platform and is played collaboratively by multiple users sitting around the STARS-table. The players have to survive together in an inhospitable environment, relying on each other's special abilities to face different task in the game. In special situations the players can also act as lone warriors to collect treasures which are hided from the other players. These private interactions are performed through a handheld device which allows each player to access the inventory and special abilities of the own game character. The hardware setup of KnightMage consists of an embedded display in the table and a wall display, where participants can share relevant information to other players. All the hardware components are part of the STARS [18] platform, and were originally developed as part of the roomware project [24]. The STARS platform is designed to support classical board games with the use of various multimedia-devices. With the use of several displays which can either be public or private displays the STARS setups allows developers to create very complex game scenarios which can for example both collaborative and competitive elements in one game. Setup components include a touch sensitive plasma display which acts as the game board and which is coupled with a camera capturing the setup from the top. The camera allows the system to detect and identify game pawn on the interactive screen. In addition to that the table includes RFID readers which in combination with RFID tagged objects can be used to save and load different scenarios and games. The STARS system also puts a strong focus on providing audio channels to communicate with the users of the system. Both public messages via loudspeakers and private messages via earphones are can be delivered by the system.

B. Weathergods

Weathergods [1] is a round-based game which can be played by up to four players simultaneously on the Entertaible [16] system. Each player has three different pawns which can perform different actions in the game. The goal of the game is to earn enough gold to be able to buy oblations to please the weather gods. Gold can either be earned by selling camel milk, robbing other players or detecting gold in the soil. The virtual game environment helps the players by displaying possible pawn movements and reacting to the action of the players. Special attention was paid to the very iconic style of the pawns which are tracked by the tabletop surface. The game is played on the Entertaible which uses an embedded LCD-screen to display interactive graphics [16]. The optical tracking system allows the simultaneous detection of up to 40 interaction points. The technology uses infrared LEDs and infrared phototransistors to which are integrated in the frame around the screen. Due to the fact that the system uses infrared, it is independent from different lighting conditions and can therefore be used in different locations. The tracking system enables the Entertaible to detect both special game pawns and direct touch input. The pawns that are placed on the screen are manufactured from a translucent material which transports the light to the top of the pawn based on total inner reflection. This way by changing the underlying pixels on the screen the color of the pawn can be changed. The Entertaible was developed by Phillips and is designed for the use in common rooms and bars.

C. Augmented Coliseum

In Augmented Coliseum[15] the players can control real robots which are fighting each other using virtual weapons. The game uses a top-projection setup to display the virtual game components. Special projected marker patterns are used to control the robots on the table's surface. The robots have several embedded photo sensors which measure the brightness of light projected onto them. Whenever the pattern is moved across the table surface the robot automatically follows the pattern. In the game up to two players have various offensive and defensive weapons at their disposal which they have to use to destroy the robot of the other player. The destruction of the enemy's robot is shown by a virtual explosion.

D. Warcraft 3

Tse et al. [26] present a multi-touch and multi-user gaming environment which is based on the DiamondTouch table [6]. The users can play the game Warcraft 3 by Blizzard Inc. using direct touch input, gestures and speech interaction. The multimodal approach also allows users to combine different interaction metaphors to perform more complex tasks in the game. Direct touch can be used to command units in the virtual game environment whereas gestures are used to select units or navigate the virtual world. Speech commands can be used in combination with pointing gestures and are used to trigger specific actions of the selected units.

The DiamondTouch system developed by MERL [11] is the first commercially available tabletop tracking system. Therefore extensive research has been conducted on interaction techniques using the system [19][23]. The DiamondTouch comes in two different sizes (32 and 42 inches) and allows the simultaneous tracking of up to four people. The tracking of the input points which can also distinguish between different users is done using electrical fields. Users have to sit on special mattes. While touching the surface of the Diamond Touch, the user closes an electric circuit and special antennas, embedded in the frame detect the user's interaction. Notice that every mate is connected to a different sender. Therefore, the table can also distinguish between different users. The interpolated resolution of the Diamond Touch table is 2736 × 2048 points and the table can read out tracking information with a refresh rate of 30Hz. An advantage of the DiamondTouch is the fact that objects placed on the tracking surface do not interfere with the system.

Our work is influenced by the previous work, but it is different in a number of important ways. Our system benefits from the following features:

- Seamless combination of both real and virtual data combined with augmented content,
- digital objects can trigger actions on real objects and vice versa,
- flexible and accurate pen tracking technology for simultaneous multiuser interaction with virtual objects,
- participants have to work with both real and virtual objects for solving a task, and
- participants should not have to wear special hardware devices (e.g. HMDs) for visual feedback of the system.

III. COMINO – THE GAME

Comino is a collaborative tabletop game for up to four players who have to solve a puzzle using both real and digital domino tiles. To link both worlds, we implemented special physical interfaces (see Fig. 4).

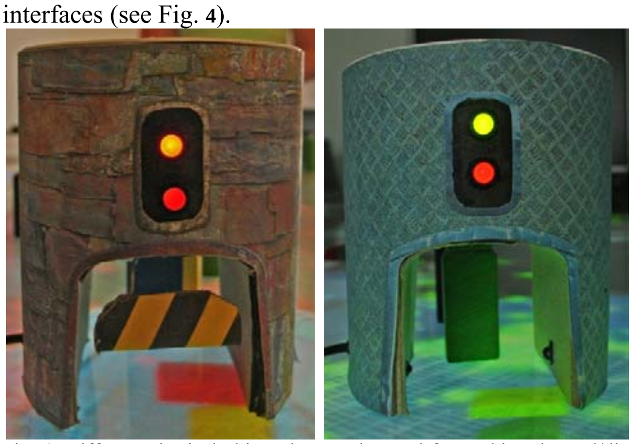
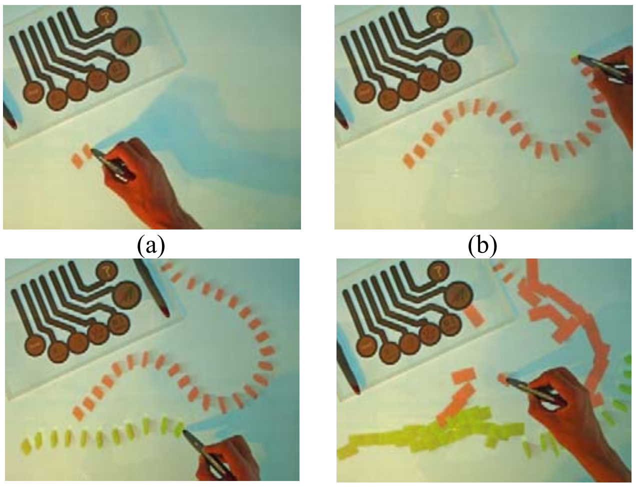


Fig. 4: Different physical objects have to be used for pushing the real/digital domino pieces. The actuator of the first tower can push real domino tiles. The photo sensor of the second tower can track the falling physical piece and push the digital ones.

Using the wireless pen-interface, players can *draw* a path on the table's surface for placing the digital (projected) domino tiles (see Fig. 5). Since our system is based on a physics engine, even the digital tiles can topple down by awkward handling.



(a) (b)
(c) (d)

Fig. 5: The digital domino pieces are placed with a digital pen. The physics engine allows a natural interaction with the environment.

The players can select between different actions, set up domino pieces, re-position, or delete domino pieces. At the same time, other users can start setting up real domino pieces directly on the same surface of the back-projection table, creating a very strong mixed reality experience. While playing, the users can move freely around the table. Comino has no dedicated mode for setting up the domino pieces. Hence it happens quite often that either the real or the virtual domino pieces start toppling over before the chain-reaction is started by the users, forcing the users to work together even more. The tension of the players is at its peak once everything is set up, the chain-reaction is started and everybody is hoping for his part of the domino line to work until the last block has fallen down and the game advances to the next level.

Fig. 6: Comino in action. Up to four people can interact simultaneously with the system and place both real and digital domino tiles.

In some cases, users need to switch to the real world using custom-built physical portals (see Fig. **4**) that allow a physical impulse to be "transferred" to the physical world and vice versa. Hence digital domino tiles can cause real domino tiles to topple over and the other way around. The setup is based on a rear-projection table with a special surface that allows to simultaneously localizing multiple digital pens. Using these pens, the players can position virtual domino tiles on the projected surface. The terrain also constrains the area where the stones can be placed.

IV. IMPLEMENTATION

Fig. **7** depicts the system outline of the tabletop game Comino.

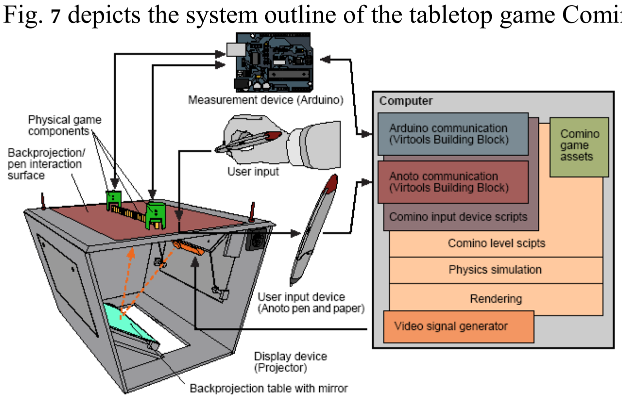


Fig. 7: System outline. The physical objects are based on Arduino's technology, while the digital domino pieces are placed by using Anoto pens. The rendering is realized with Virtools.

The four main parts are:

- rear-projection table,
- the physical game components,
- digital pens,
- and the Comino software.

The main interface is the interactive table on which the user can place the domino pieces. Notice that we neither track the position of the real pieces nor we track the position of the physical towers. The levels (currently we implemented three different levels) are scripted in Virtools. The physical simulation engine allows a natural behavior of all digital objects. Finally, we also integrated special visual effects (e.g. shadows, reflections, particle systems) to enhance the rendering quality.

A. Game Table

The table uses a projector (including a mirror) and a special back projection surface to display computer generated images on the tabletop. The height of the table is approximately 90cm which allows convenient interaction while standing around the table.

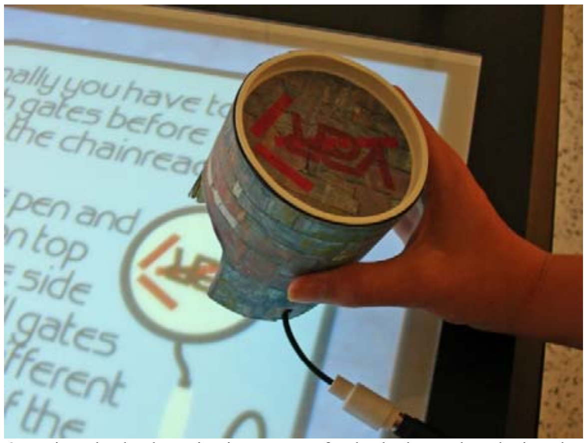


Fig. 8: Using the back-projection screen for both the real and virtual game components allows the display of dynamic help for the physical game parts.

In our setup (see Fig. **9**), we used an A0-sized rear projection surface (112.0cm × 85cm). In Comino, we used a semitransparent HP Colorlucent Backlit UV foil as projection surface. The foil is also used as tracking surface for the Anoto pens which were used as user input devices [3]. The pattern, printed on the foil, is clamped in-between two acrylic panels. The panel in the back has a width of 6mm and guarantees a stable and robust surface while the panel in the front has a width of only 0.8mm to protect the pattern from scratches. We noticed that the acrylic cover in the front does not diffract the Anoto pattern at all. However, using thicker front panels (e.g. ≥4mm), produces bad tracking results.

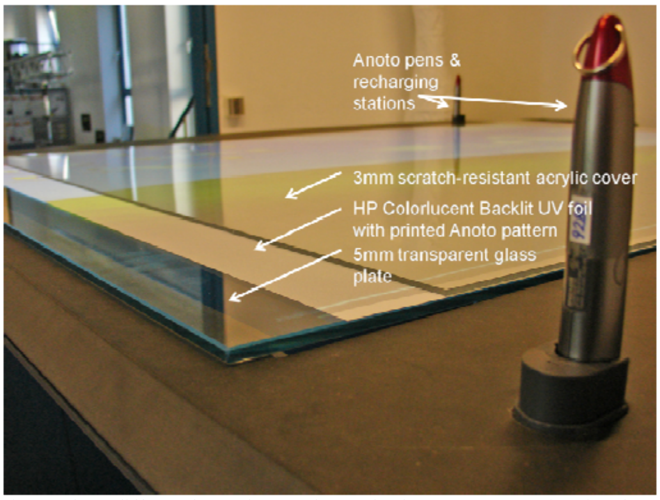


Fig. 9: Three different layers have to be used: The Anoto pattern is printed on an HP color lucent backlit UV foil, which is clamped in between two acrylic glass plates.

Before the use of the pens, the Anoto pattern is calibrated with custom written software to fit the projected image, allowing fast and accurate tracking of multiple pens. The rear-projection screen also acts as the game surface for the physical game components. Hence, the physical parts can be augmented with virtual content and dynamic virtual help screens (see Fig. **8**).

B. *Digital Pens*

The digital Anoto pens of our systems are using an infrared light based camera, which tracks the underlying pattern (see Fig. **10**).

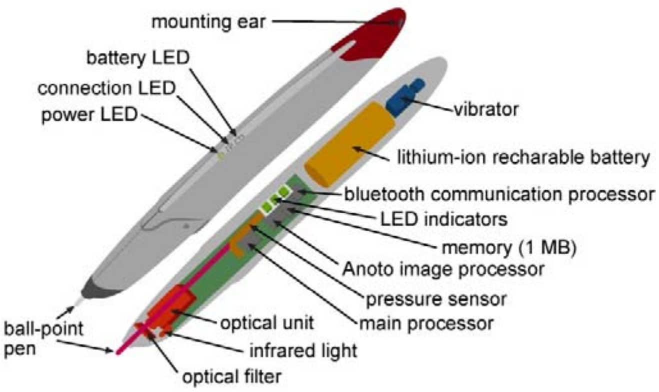


Fig. 10: The Anoto pen sends data over a Bluetooth connection.

Anoto-based digital pens are ballpoint-pens with an embedded infrared camera that tracks the pen movements simultaneously. The pen has to be used on a specially printed 600dpi paper with a pattern of small dots with a nominal spacing of 0.3mm.

C. *Real and virtual objects*

The interaction between the real and virtual game components was realized using custom built hardware interfaces (so called portals) and Arduino microcontrollers [10]. Setting up the game's physical components is also part of the game-play. Therefore, the microcontroller was integrated in an enclosure (so called sensorbox) ensuring that the players could not destroy the Arduino board by erroneous wiring or mishandling. Both the sensorbox and the portals were equipped with color-coded Mini-Din-connectors facilitating the setup of the physical game components and preventing short circuits and possible damage of the portals. The sensorbox is connected to the host computer via USB, allowing real-time serial communication with the game-engine (see Fig. **11**).

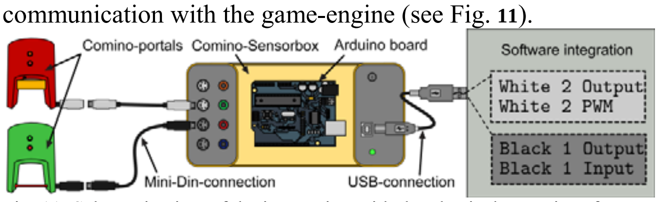


Fig. 11: Schematic view of the interaction with the physical game interfaces.

The virtual counterpart or link to the physical interfaces are special "portal domino bricks" which cannot be modified by the user. These special domino elements are placed on a fixed location in the virtual environment and indicate where the physical interface should be placed by the players for the chain reaction to work as intended. Fig. **12** illustrates the interaction between virtual and real domino bricks in Comino.

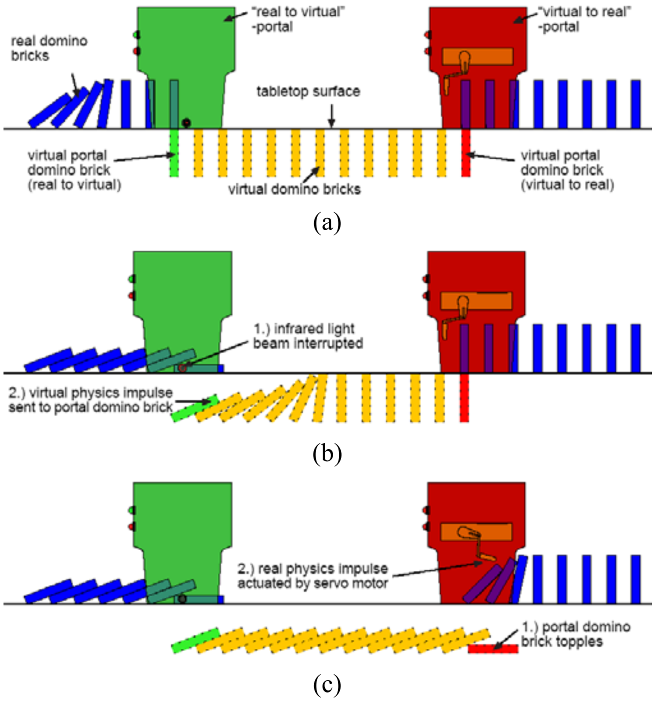


Fig. 12: Special "portal domino bricks" act as virtual counterparts to the physical interfaces, allowing the transition from the real to the virtual world and vice versa.

In the example shown in Fig. **12** the chain reaction starts in the real world. After toppling over, the last of the real domino blocks interrupts the infrared light beam which is emitted by an infrared LED integrated in the first portal. This change in intensity is detected by an infrared photodiode which is mounted on the opposite side of the portal and gets sent to the game via the Arduino board. In the engine, this change triggers a virtual impulse which causes the associated portal domino brick to topple over. The chain reaction can now continue in the virtual realm. If the virtual domino bricks are set up correctly the chain reaction will now knock over the other portal domino pieces. This will trigger a real physics impulse actuated by the servo motor integrated in the second portal, causing any real domino block placed under the portal to topple over. Now the chain reaction is back in the real world, the interaction cycle is closed.

D. Software Implementation

For software development Virtools was chosen [13]. Virtools is a real-time 3D authoring environment which allows the creation of interactive 3D content. Virtools features a graphical programming interface which allows authors to create complex applications by dragging behaviors (or Building Blocks (BBs)) in scripts which are then assigned to various game objects (see Fig. **13**). Virtools can also be extended using the Virtools SDK and C++. For Comino, two custom BBs where implemented which facilitate the direct communication with Arduino and Anoto and the Virtools application. Both the Arduino and the Anoto BB are designed to be very flexible, permitting both BBs to be easily integrated in other Virtools projects.

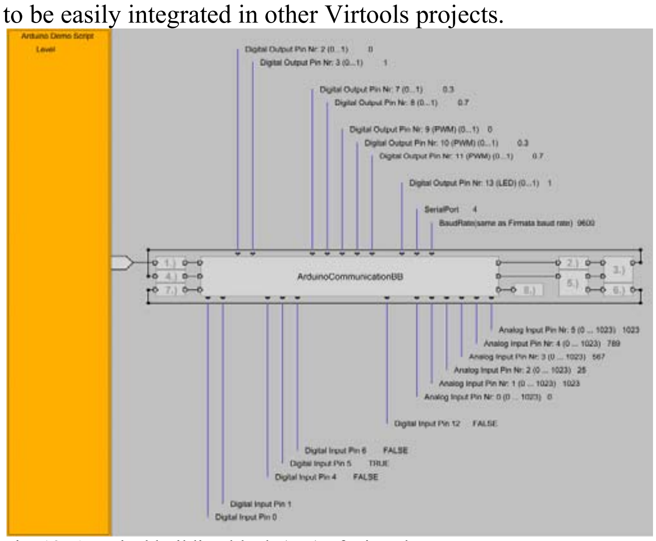


Fig. 13: A typical building block (BB) of Virtools.

The Anoto BB works as a UDP-receiver and works in combination with a custom UDP-sender which is able to read the Anoto-pen data via the Bluetooth port. The UDP-sender was developed at our University and was successfully used in various projects using Anoto-pen user input. For Comino, a BB which can handle up to four pens simultaneously was developed. This number was chosen because of the maximum number of players, which was decided to be not more than four players because of the limited amount of space provided by the hardware setup. However, the maximum number of pen can easily be increased for future projects. The calibration of the pen tracking is done using custom implemented software which allows the specification of different interaction areas (drawing areas, sliders or buttons) on any number of Anoto enabled surfaces. The calibration data is saved in an XML-format and can be interpreted by the Anoto BB, allowing fast and flexible configuration without recompiling.

The Arduino BB was also designed to allow very flexible integration of the Arduino board in Virtools. Instead of just integrating the functionality needed for the game, the Arduino BBs provides total control over the Arduino board within Virtools, redefining the functionality of the Arduino board to a plug-and-play sensorbox which no longer needs special programs running on the controller itself. Using the Firmata protocol [10], all analog and digital I/O-pins of the Arduino board can be read or set from within Virtools without the specific knowledge of the Arduino programming tools and language. Hence even the novice users can easily integrate physical computing functionality in their Virtools project.

Comino features custom created game assets which were created using various 2D and 3D programs and then imported into the Virtools application. To create a more realistic and immersive game experience, physics simulation was integrated in the game for a realistic behaviour of the virtual game objects and a more seamless transition between real and virtual game objects. For the physics simulation, the Virtools Physics Library was used.

V. EARLY USER FEEDBACK

In our initial pilot study we tested 12 people (6 groups) from our University, who were not affiliated with this project. The overall participants' reaction was very positive. Users really liked the idea of playing with a tabletop interface that combines the real physical objects with a digital (augmented) environment. Participants had the impression to play within *one* world. The interface was perceived as very intuitive since the virtual domino pieces are behaving the same way as the real once.

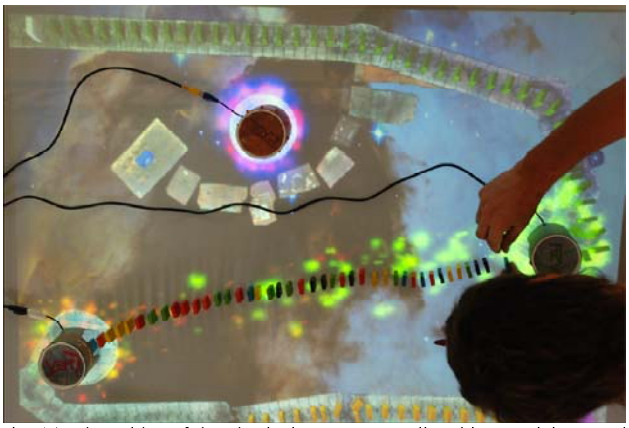


Fig. 14: The cables of the physical towers were disturbing participants while placing the domino stones.

Users also had no problems to use the digital pens for placing the virtual domino pieces. The tracking results of the Anoto pens are fast and allow users to perform an accurate interaction. However, they had difficulties handling with cables of the physical towers, which were placed on the table's surface (cf. Fig. **14**). A possible alternative would be the use of Bluetooth (BT) Arduino boards which could directly be integrated in the towers and would eliminate all cables. However, apart from being more expensive, this solution would also need a power supply in the towers and a re-implementation of the Firmata protocol which was designed for the use with the USB-boards only.

One of the design goals was to avoid HMDs and heavy, cumbersome devices for tracking the users' head position and orientation. Consequently, we had to find a rendering perspective which looks fine for most perspectives. In some special cases (if the users are looking to the scene with a really flat angle) users can have a distorted view of the scene (see Fig. 15).

Fig. 15: In some cases the perspective of the domino piece can become distorted.

Finally, the application also encouraged the close collaboration between the players (see Fig. 15). In order to solve the task, all involved players have to discuss their strategy and be aware of what the co-player is doing.

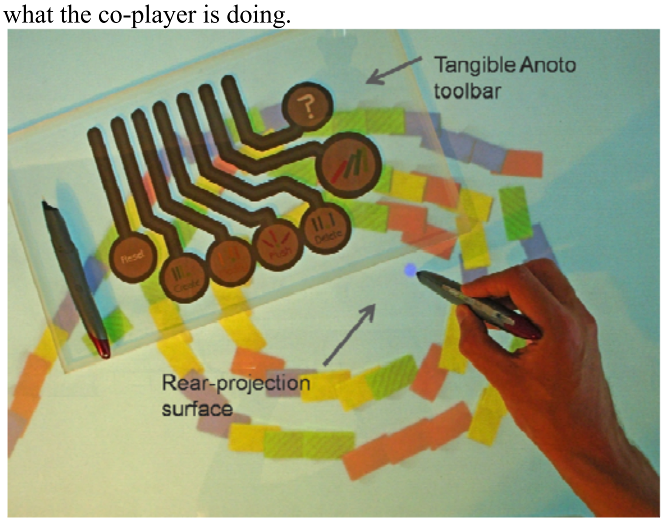


Fig. 16: The transparent tangible toolbar allows participants to use special functions. Again on top of a Plexiglas, we put a pattern marker, which can be easily tracked with the digital pen.

Fig. **16** depicts the interaction also using a transparent tangible tool (e.g. control panel), which allows users to interact with the game (e.g. change the interaction mode).

VI. CONCLUSION AND FUTURE WORK

In this paper, we have presented a new tabletop game interface, where both the real and digital world has to be connected to solve a task in the game. The presented Comino game allows users to play with real and digital domino tiles. The seamless integration of the digital content in the real environment worked fine. The results we achieved in our first user study present that participants had the impression to play in one world.

Our ongoing work will continue to add new physical objects (e.g. small robots from [15]) which also allow crossing the border between the real and digital world. Moreover, we are planning to scan the table surface with a Z-Sense camera [9] for a better physics behavior of the digital domino pieces.

VII. ACKNOWLEDGMENTS

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