Robot in the Garden: Preliminary Experiments Programming an On-site Robot Ball Assistant to the Landscape Architect

Caroline Westort[1], Zhongzhe Shen[2]

[1]Iowa State University College of Design, Iowa/USA · westort@iastate.edu
[2]Iowa State University College of Design, Iowa/USA · zhongzhe@iastate.edu

Abstract: The project features preliminary experiments programming a small autonomous robot ball known as the SPRK+ Sphero that explore the utility of an onsite robotic "assistant" to the landscape architect, and ask the following research questions:

i. What useful work can an interactive robot ball offer a landscape architect on site?

ii. What would an initial prototype implementation look like?

First results include exploratory implementations using the OVAL SDK for Sphero for calculations of position, distance, collision, and by extension, slope and area. The project is innovative in three respects: 1) It uses an off-the-shelf handheld, low cost robotic toy as a first experimental implementation, 2) It identifies characteristics of an on-site robotic assistant that would make it useful to the landscape architect, and 3) It defines for implementation key initial starting tasks that the robot ball could perform. Several short demo videos showcasing our first results accompany the paper.

Keywords: Robotics, landscape computing, in-situ landscape architecture assistant, Sphero development

1 Introduction

This paper considers robotics as a means to assist the landscape designer 'in-situ' in the field. We present preliminary experiments programming a small, low-cost, robotic ball *Sphero* that fits in the palm of a hand, and is marketed as a toy, to explore how it could assist the landscape architect. The goal of the paper is to lay out a conceptual framework to help establish the priorities for a prototype implementation. After offering our motivation behind the project, we discuss some relevant definitions and concepts pertaining to landscape robotics, survey relevant research, outline our research questions and approach, and then describe our preliminary programming experiments and first results. We discuss the implications of the work, suggest promising directions for future inquiry and work, and extrapolate some conclusions.

1.1 Motivation

The key benefit a field-based robot assistant offers the landscape architect is a closer coupling of the kinesthetic experience of occupying the landscape with robot-provided quantitative understanding. Through real-time analytics, interaction, independent mobility and enhanced site access and coverage, qualitative and quantitative factors are more closely linked. This link empowers the landscape architect by enabling more of the design process to take place at **one-to-one scale**, and phenomenological factors like light, wind, colors, sounds – i. e. the non-quantifiable or qualitative site experiences – to be considered in **juxtaposition** and **simultaneously** with the measurable factors.

Journal of Digital Landscape Architecture, 2-2017, pp. 223-234. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-629-1, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537629023.

1.2 Background

Robots in the garden are not new. Beyond the machines which have existed in the landscape since the dawn of technology – through agriculture, industrial revolutions, and now digital means – robots are unique in their ability to learn and adapt to their environment. A brief overview of the state of research on robots in the landscape can be sorted into the following categories: robots for construction or defense, robots simulating nature or natural phenomena including human experience of robotic simulations, and robots as human companions or 'droids'. First we clarify some useful concepts about the topic area.

1.3 Robotics, Automation, Sensors

Robots and autonomous systems use a combination of computer programming and sensors to customize desired behaviors and responsiveness. Robotics is distinct from automation, because robots are programmed to adapt and learn from tasks they are programmed to do, versus simply automate repetitive tasks. A robot is a machine capable of carrying out a complex series of actions automatically, especially actions programmable by a computer (DENG 2015). A sensor is "a device that detects or measures a physical property, and records, indicates, or otherwise responds to it" (GOTS 2012). Sensors are ubiquitous in the landscape; for tracking of natural phenomena, like landslides, silt deposition, settlement of structures, current, water depth, etc.

Sometimes characterized as "companions," robots are often developed to take on human-like behaviors as they attempt to offer useful work to the user (ROBOT COMPANIONS 2017). Martin Ford in *Rise of the Robots* (FORD 2015) describes the robot as a "worker", not a "machine" who may someday take over your job. Ford claims there has been "a fundamental shift in the relationship between worker and machines" that "challenges one of our most basic assumptions about technology: that machines are tools that increase the productivity of workers. Instead machines themselves are turning into workers". Robots, Ford claims, are taking over jobs and "blurring the line between … labor and capital".

The "routine" or "predictable" aspects of jobs, Ford says, are the ones that will be subject to be robotized. So the task of designing a robot ball assistant to the on-site landscape architect is, in part, an exercise in determining what tasks are routine and predictable. One could argue that there are few endeavors less 'routine' than the creative design process. Yet, there are tasks associated with site design that are predictable, such as calculating basic site metrics like position, distance, area, volume, line of site, and slope, which make the task of computing these factors a good place to start for a robot.

2 Prior Work: Robots in the Garden

2.1 Robots for Construction, Defense, Road Travel

Recent decades have experienced a proliferation of robots in the earthwork construction field via automated machine guidance and control (AMG). Also referred to as 'robo-dozing' (WESTORT 2003), or 'GPS-guided construction' AMG systems have been around for some years to automate the construction of earthwork. AMG is thought to catalyze convergence and realignment of existing *tools*, *tasks*, *locations* and *traditional disciplines* to realize automation of earthwork construction (WHITE et al. 2015). Though involving AMG earlier in the design process for iterative exploration of alternative earthwork designs would offer the exciting prospect of designing at one-to-one scale, doing so is a resource-prohibitive undertaking. Though virtual reality helmets and other kinesthetic studies on augmented reality for immersive experience are promising ways to explore this opportunity at low cost (DUPZYK 2016).

Robots are used extensively in the landscape for defense purposes. Mine detection and clearance (BHARATH 2015), un-manned tanks and drones (VINCENT 2016) are a few military uses for robots 'in the field'. Mine detection and clearance relies on metal detection and electromagnetic wave processing – not a core concern of the onsite landscape architect typically. Un-manned tanks leverage positional and navigational accuracy, situational awareness and real-time interactivity that is similar to capabilities used by "driverless" vehicles for road travel. This paper does not take on the scale or complexity of these proprietary systems, opting instead for the pared down and easily accessible functionality of off the shelf options for a proof-of-concept implementation.

2.2 Robots Simulating Nature or Natural Phenomena, Including Human Experience of Robotized Natural Phenomena

Robots developed to simulate natural behaviors or textures include squishy, deformable robots (KNIGHT 2014), robots simulating specific animals or creatures, e. g. dogs (ROBOT COMPANIONS 2017), clams (KNIGHT 2014), fish (ROBOTIC-FISH.NET 2017), frogs (ARMITAGE 2015), termites (GIBNEY 2014), etc. Robots are being developed to simulate swarms and swarm behavior (CASSIDY & VARNER 2015) which could be an exciting extension to this project. "We … program cells like little robots. Now we're programming robots like cells," says Kara Helmke, the Education and Outreach Coordinator who commands the kilobot swarm at UCSF.

Peter Kahn in his book, *Technological Nature* discusses "technologies that in various ways mediate, augment, or simulate the natural world" (KAHN 2011). He discusses the following three experiments: 1) High definition television (HDTV) "windows" – A comparison of the physiological and psychological effects of experiencing a technological nature window view to those of experiencing a glass window view of the same scene and no view at all. 2) Robotic dog AIBO – a study of how people conceptualize AIBO, including preschool children behavior with and reasoning about AIBO compared to a stuffed dog and a live dog. 3) Telegarden: a garden in Austria created by Ken Goldberg and his colleagues that allows remote computer users to plant and tend seeds by controlling a robotic arm through a Web-based interface.

The distinguishing characteristic of these robotic efforts is that the robot either represents a manifestation of nature, or human experience of the robot is the focus. The target concern in this project is the use of robots to enhance and augment human experience and understanding of the environment, which both the robot and human occupy and move through, such that the robot can perform useful work.

2.3 Robots as Companions/Humanoids/Androids

A companion robot is one that is capable of providing useful assistance in a socially acceptable manner. This means that a robot companion's first goal is to assist humans. Robot companions are mainly developed to help people with special needs such as older people, autistic children or the disabled. They usually aim to help in a specific environment: a house, a care home or a hospital (CHANSEAU 2017, ROBOT COMPANIONS 2017). The Buddy android (BLUE FROG ROBOTICS 2017, ROBOT COMPANIONS 2017) is a "cognitive robot whose 'purpose in life' is to serve humans as an assistant or 'robot companion.'…able to learn new skills and tasks in an active open-ended way and to grow in constant interaction and co-operation with humans" (BLUE FROG ROBOTICS 2017, ROBOT COMPANIONS 2017). Four categories of functionality are offered by Buddy. We try to extrapolate these to the landscape design project site: Detect, Calculate, Report/communicate, Trace/Follow.

2.4 Characteristics of a Robot Assistant to the Landscape Architect

An on-site robot assistant would therefore need to possess the following characteristics:

Mobility – The ability to move around the site over different kinds of terrain.

Positional accuracy and awareness – The ability to know its three-dimensional position at any given place on site, and to compare that position to that of the user or other relevant on or off site locations. The ability to detect and interpret the weather and material conditions of a site.

Communication and interaction – The ability to communicate in real-time to and from the user as well as between remote computers or off-site design team members or project stakeholders.

Computation / Processing – The ability to conduct relevant calculations, e. g. distance, scale metrics, line of sight calculations, slope, area, and cut and fill volume. The ability to compare, analyze, draw conclusions and even offer suggestions to the designer based on these calculations. This characteristic is closely linked to the Adaptability characteristic below.

Ruggedness – The ability to be weather-proof and sufficiently durable to traverse perhaps 'unfriendly', uncomfortable, dangerous terrain, in order to access locations beyond the access range of a single person, e. g., under water, over steep slopes or through unstable surface or weather conditions.

Adaptability – The ability to adapt its behavior based on what it learns is a distinguishing characteristic of robots. In the landscape, this characteristic could be expressed in several ways, e. g., "if calculation of an area exceeds some threshold size, revise the distance between tree plantings according to some criteria, and indicate the new tree locations as we move around the site." Or, as the landscape architect scales a hill and indicates that the slope 'feels too steep', the robot could record the concern and when avigating similar slopes subsequently elsewhere on site, the robot could remind the designer that the slope felt 'too steep' previously.

These characteristics of a robot assistant point to several potential workflow advantages in the field. The landscape architect could 'task' a robot with some measurement and time-consuming tasks and save the designer from walking and collecting data. The robot-ball is small and compact and could perform similar tasks as a theodolite, a plumb line, measuring tape, level, and other gear landscape architects might haul to a site for site measurement. Since the *Sphero* robot ball claims to be weather-proof, the designer could work in inclement weather conditions and beyond industry-regulated labor windows, thereby prolonging the workday. A robot or a collection of robot balls could collect and process data more accurately and with greater efficiency. Also the simple existence of a separate autonomous, communicative, 'smart' entity that is also wirelessly connected to the user and the internet that can learn and respond appropriately, suggests companionship, fun, and an expanded set of capabilities beyond what a single site visitor could accomplish.

3 Research Questions

Taking cues from the priorities of robotic companions to do useful work and to interact with the user (BLUE FROG ROBOTICS 2017), from automated machine guidance and control (AMG) technology (WHITE et. al 2015) to work at one-to-one scale in-situ, and from our list of characteristics of what is robotically useful to the landscape architect in the field, and from the *Sphero* robot ball itself (STARK 2012, ORBOTIX 2014, MCCRACKEN 2013), we pose the following questions:

i. What useful tasks could a robot ball offer a landscape architect on site?
ii. How does one implement such tasks using the off-the-shelf SDK for the *Sphero* robot ball toy?

3.1 Research Methods

We simplified the characteristics of an on-site robotic assistant outlined above to the functional task categories: *Detect, Calculate, Report/communicate, Trace*. The following describes the preliminary experiments we undertook to program the *Sphero* to accomplish intended individual tasks, and reports on the status of the implementation at the writing of this paper.

3.2 SPRK+, Sphero

Sphero is a spherical robot toy designed by Sphero, previously Orbotix (GORMAN 2011, MCCRACKEN 2013, DENHAM 2013). It is a white orb that weighs 0.37 pounds (170 g) (ROBERTSON 2012) wrapped and completely self-contained and sealed in polycarbonate plastic, that is both self-propelled and under remote computer control connected via Bluetooth with a smartphone or tablet running iOS, Android or Windows Phone, and wirelessly charged with a charging base (MCCRACKEN 2013, STARK 2012). There are "nubby" covers sold that increase traction/durability over rougher terrain (like a carpet), and also through water. Several apps and games have been developed for the platform (MCCRACKEN 2013, STARK 2012) and the toy can be used as a controller for games on iOS and Android platforms (SAVITZ 2013, ORBOTIX 2014). Sphero's firmware is updated automatically with the official app (ORBOTIX 2014). Users can program the toy with an app called *Sphero* Macrolab which includes a set of predefined macros, Lightning Lab which does the same, orbBasic which uses a BASIC-based language, (SPRK WEBPAGE 2017) or the recently released OVAL SDK, which is a C-based language block programming environment that this project uses (GOTS 2012).

Small, autonomous robots like the *Sphero*, are commonly regarded as toys, household aids, or are associated with the gaming industry. Their size and affordable cost offer the advantages of low overhead, a developed and dedicated online community, and a standardized software development kit (SDK) with which to customize and experiment (Wikipedia, Sphero).

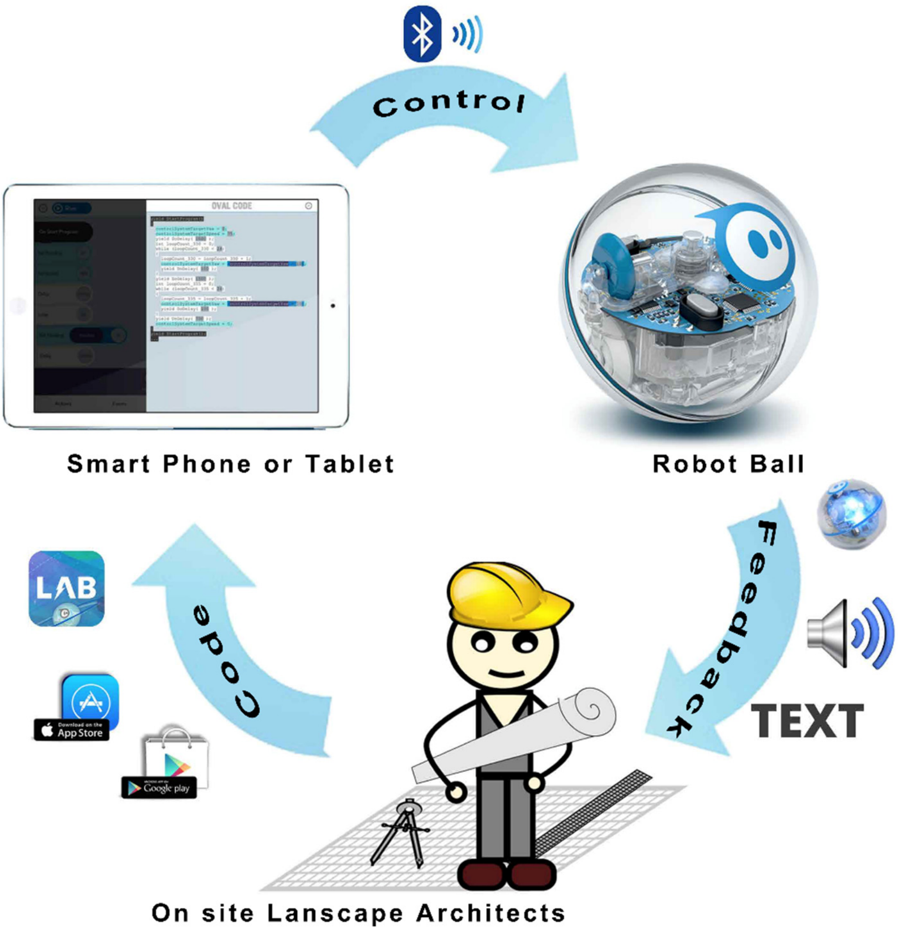

Fig. 1: Workflow of the *Sphero* concept

The project uses off the shelf and customized programmed components. *Sphero* comes with an available SDK to develop applications that can interact with the ball, with unofficial SDKs also available for other devices and platforms. This project utilizes the recently released OVAL programming language as an SDK plugin as its starter development platform. The following is a list of *Sphero* actions possible 'out of the box':

***Sphero* Actions – out of the box:**

- Roll distances up to XX away
- Stop specified distances away
- Speak
- Illuminate
- Blink
- Change color
- Spin

4 Tasks and First Results

We describe the preliminary experiments we undertook to program the *Sphero* to accomplish specific tasks, and we report on the status of the implementation at the writing of this paper.

4.1 Detect: Position and Distance, Collision, Weather and On-site Conditions

Position and Distance

Goal: Not unlike a site 'surveyor', locate an accurate 3-dimensional position of the *Sphero* in horizontal and vertical space anywhere on site, either relative to the user, or in geo-referenced space

Status: See VIDEO 1 and VIDEO 2. Current assumption is that the ball travels in a straight line on a flat, less than 5 % sloping, surface. Relative position from the user's tablet is calculated, using the speed and time sheet measurements offered on *Sphero's* official website. For example, assigning the ball a speed of 60 cm/second means the robo-ball flashes red after each 100 feet, green every 10 feet, and blue every 1 foot. The current maximum speed available to the *Sphero* is 255 cm/s. For very long ranges, the user can customize the code to calibrate the light flashing to longer distances.

Collision

Goal: To detect and locate obstacles that the robot ball cannot circumnavigate in the field.

Status: Using the relative position from the user's tablet together with the speed and time sheet measurements offered on *Sphero's* official website, a collision is detected when the accelerometer indicates the roll function has been obstructed by the ball remaining stationary. When the robo-ball encounters a barrier, the ball stops and communicates its location using a flashing frequency: 1 red flash for each 100 feet, green every 10 feet, and blue 1 foot. While the ball communicates its relative position back to the tablet as text, the flashing light allows others in the field to also read the information.

4.2 Calculate: Slope, Area, Volume, and Orientation (Ordinal Direction)

Slope

Goal: Calculate the slope between 2 points. Calculate the slope at the user's position or the *Sphero's*. Calculate the elevation at any given location of the *Sphero*. Additional functionality includes calculation of the maximum slope.

Status: Currently only slopes under 2 % are possible as steeper slopes cause the sphere to succumb to gravity and roll down the slope. Even with a 'skin with treads' that the robo-ball may wear, the slopes currently possible are too gradual to be practically useful. Should a sufficiently stable tread coating be possible, however, we can attempt a method for computing slope:

Slope is determined by comparing the ball's position at any given point along the slope with a previously calibrated horizontal 0 % slope starting position.

Slope is communicated as an angle with both text on screen and the ball's flashing the value with a series of lights.

This result depends on an under 2 % slope as the robo-ball rolls down the hill if placed on a slope that is too steep.

Orientation

Goal: Point the *Sphero* to 'true' N, S, E, or W using positional information.

Status: The robot ball's orientation can be set manually in Sphero's scripting environment, Lightening Lab, where the cardinal directions can be specified for 'pointing' the robot in a particular direction. This feature canals, determines and reports as text, the orientation of the robot at any given time.

Area

Goal: Calculate a user-specified area in the field; the periphery for which would be either uploaded from a CAD drawing or traced on foot by the user in the field. This periphery would then be traced by the robot ball in the field, effectively showing the user how large that area footprint appears in situ.

Status: Currently metrics taken from a .DWG CAD file may be uploaded to OVAL and an area calculation computed.

4.3 Report or Communicate

The robot-ball communicates metrics back to the user as text, audio/sound, graphics, movement, blinking lights.

Audio-visual communication

Goal: Communicate to the user in any audiovisual mode deemed most useful by the user, including voice, text or graphic display on the tablet, and with desired behaviors and movements, colored and blinking lights. The robot can appear to nod or shake its head, for example, and blink a particular color if it agrees/disagrees, is "happy" or "sad" or "upset", etc. It can "gesture" or "point" in particular directions, it can express excitement, impatience, calmness, feeling "bummed out" through motion and speed and color of blinking lights. Such social and behavior-based communication offers the user a social connection, as any true companion would. The interaction should be 2-way; the user should be able to make requests of the ball and it appropriately respond.

Status: Currently the robo-ball responds to users with blinking lights, or numerically on the tablet screen. At this writing we are cataloguing the range of characteristics a rolling ball can express, and have begun to implement nodding and shaking back and forth to express "yes" or "no". We are also beginning to try voice/audio recognition features available with the most recent *Sphero* SDK release so the robot ball can respond to voice commands.

4.4 Trace or Follow

Trace

Goal: Trace the boundary, location or dimensions of site features in the field while drawing them to the screen. Having a robot ball outline in the field, the footprint of a particular design feature the designer has in mind, is valuable for several reasons: 1) It can be a planimetric 'mock-up" in the field of a particular design feature. 2) the robot can trace over different versions of a feature, giving the designer an opportunity to compare in-situ the scale of multiple alternatives in the field.

Status: The robot ball can trace in the field, lines of an uploaded CAD file as long as the dimensions do not exceed the maximum distance for maintaining *Bluetooth* wireless connectivity, and the terrain surface is flat and smooth. *Sphero* can only roll reliably on paved surfaces, not currently on grass.

Follow

Goal: The robo-ball could follow the user as a companion.

Status: At this writing, we are cataloguing the range of behaviors a rolling ball can express through movement and lights, and have begun to implement "heel" and "sit" behaviors first through keyboard input, to be followed by Sphero sensor recognition of the user's movement.

5 Future Work

We indicate below next implementation tasks in their respective task categories.

5.1 Position and Distance

There is widespread interest in *Sphero* offering real-time GPS positional accuracy and access. One method to pursue involves connecting the GPS of a cellphone to the Bluetooth of the *Sphero*. Another option would be to use a camera to determine location, but there is currently no camera on board the *Sphero*. *Sphero*'s SDK OVAL also offers no trigonometry functions, though they are promised to be in a release soon.

5.2 Weather and On-site Conditions

The *Sphero* is marketed as being waterproof and able to roll, able to maintain a blue-tooth connection, flash its lights, change direction, and otherwise function under water. The ability to detect this would obviously be desirable for the landscape architect in the field. It is also desirable to know what material the Sphero is rolling over, e. g., asphalt, concrete, grass, gravel, mud, etc.

5.3 Volume

Calculation of cut/fill volume quantities from a combination of user and CAD file input values is a broadly desired functionality with which this project plans to experiment.

5.4 Audio-visual Communication

At the writing of this paper, we are cataloguing the range of movement behaviors a rolling ball can express and have begun to implement nodding and shaking back and forth to express "yes" and "no" gestures. OVAL has indicated that voice recognition and other functionality will be available in next releases. Here is an example from another app we would like to emulate (SPRK WEBPAGE 2017)

5.5 Swarms

The prospect of 'unleashing' a 'swarm' of more than one robotic ball into a design site, with each robotic ball having an identity as a member of a larger group or 'swarm' of robot balls. Responding to others in the group is an exciting extension to this project, particularly when specific site conditions and user interaction can influence the swarm's collective behavior.

The videos included with this paper attempt to showcase the status of our initial implementation prototype and to show how several functions continue to need to be block coded directly into OVAL. Next implementations will allow greater interactivity and translation with CAD drawings, making area and volume calculations more immediate. Voice recognition will boost the robot's user friendliness and decrease the need for the user's 'expert knowledge' to hard code directly into OVAL. For *Sphero* to successfully be the platform to accomplish this, the robot ball would have to improve the range of its available wireless connectivity. Currently a maximum of 30 feet is possible in an un-obstructed environment.

6 Discussion and Conclusion

The landscape architect's ability to actively design while in the field – to generate, revise, and analyze alternative design scenarios in three dimensions, at one-to-one scale, and in real-time – is currently not possible due to the following limitations:

i) Accurate site information that can be queried is rarely available or modifiable in the field; metrics like 3-dimensional position, scale, line of sight calculations, slope, area, and cut-and-fill volume are not currently available in-situ.

ii) Proposed design alternatives in three dimensions are not visible on site – though Virtual Reality head-mounted displays show much promise to help with this.

iii) Use of automated machine guidance and control (AMG) technology to construct design alternatives at one-to-one scale is cost and resource prohibitive to do iteratively in the field.

The potential benefit of a portable, inexpensive, onsite robot to significantly assist the landscape architect creatively is considerable. In addition to being fun, useful and novel, a robot ball companion assists the landscape architect with functions beyond the task list generated in this paper. The landscape designer's question, "How does it feel to walk up that hill?" could be answered more rigorously with the input of a companion robot assistant offering on-site quantitative understanding of that hill *while the designer is climbing it*. The robot could help the designer generate other hills based on the dimensions of the first by:

- Tracing alternative footprints in the field at one-to-one scale for the designer to consider and compare. The combination of on-site metrics, full scale immersion, and interactive modification of alternative design scenarios would improve designs by simultaneously vetting the viability of alternatives.
- Recording when the designer felt a particular slope was too steep or too gradual, and communicating these perceptions back to the designer when similar slopes are experienced or considered subsequently. In so doing, the robot's ability to learn and adapt based on prior experience, as well as communicate interactively and in real-time, makes it a "smart" and valuable companion.

- Communicating to the user in multiple modalities – graphics, tracings in the field, lights flashing, motion behaviors, audio – the robot would contribute to a site visit experience made more friendly, safe, and interactive.

While our technical results are preliminary, we believe the insights gained offer a promising conceptual basis for pursuing the project further.

References

ARMITAGE, H. (July 9, 2015; 2:00 PM), Video: A Robot That Hops like a Frog. Science | AAAS. http://www.sciencemag.org/news/2015/07/video-robot-hops-frog (July 9, 2015).

BHARATH, J. (2017), Automatic Land Mine Detection and Sweeper Robot Using Microcontroller, Vol. 4, No. 1, January 2015 – IJMERR. http://www.ijmerr.com/index.php?m=content&c=index&a=show&catid=126&id=413 (April 22, 2017).

BLUE FROG ROBOTICS (2017), BUDDY: THE COMPANION ROBOT ACCESSIBLE TO EVERYONE. http://www.bluefrogrobotics.com/en/buddy-your-companion-robot/ (February 15, 2017).

CASSIDY, J. & VARNER, J. (July 21, 2015), Can A Thousand Tiny Swarming Robots Outsmart Nature? KQED Science. https://ww2.kqed.org/science/2015/07/21/can-a-thousand-tiny-swarming-robots-outsmart-nature/ (April 1, 2017).

CHANSEAU, A. (2017), Robot Companions Are Coming into Our Homes – so How Human Should They Be? The Conversation. http://theconversation.com/robot-companions-are-coming-into-our-homes-so-how-human-should-they-be-63154 (April 21, 2017).

CRUISE, S. (2016), Sphero Azure GPS. Hackster.io. https://www.hackster.io/michstmatt/sphero-pilot-62f1be (January 12, 2017).

DAVIDSON, D. et al. (2010), Beyond Fun: Serious Games and Media. Pittsburgh, Penn.: lulu.com.

DENG, B. (July 2, 2015), Machine Ethics: The Robot's Dilemma. Nature News 523, No. 7558 24. doi:10.1038/523024a.

DENHAM, E. (September 19, 2013), Robotic Play Teaches Kids Math and Programming. Huffington Post.

DUPZYK, K. (2016), I Saw the Future Through Microsoft's Hololens. http://www.popularmechanics.com/technology/a22384/hololens-ar-breakthrough-awards/ (April 25, 2017).

EUROPEAN ROBOTICS PROJECTS ... BEYOND THE ROBOTICS UNIT AT THE ERF 2015, Digital Single Market. https://ec.europa.eu/digital-single-market/en/news/european-robotics-projects-beyond-robotics-unit-erf-2015 (February 20, 2017).

FORD, M. (2015), Rise of the Robots Technology and the Threat of a Jobless Future. Basic Books, New York.

GIBNEY, E. (2014), Termite-Inspired Robots Build Castles. Nature News (April 1, 2017). doi:10.1038/nature.2014.14713.

GORMAN, M. (December 19, 2011), Orbotix Sphero review. Engadget.

KAHN, J. (2011), A digital pioneer questions what technology has wrought. THE VISIONARY, July 11 & 18, 2011 Issue. http://www.newyorker.com/magazine/2011/07/11/the-visionary.

KAHN, P. H. JR. (2011), Technological Nature: Adaptation and the Future of Human Life. MIT Press, Cambridge, MA, USA.

KNIGHT, H. (March 24, 2014), 'ROBOCLAM' HITS NEW DEPTHS AS ROBOTIC DIGGER (W/ Video). Phys.org. https://phys.org/news/2014-04-roboclam-depths-robotic-digger-video.html (April 22, 2017).

KNIGHT, H. (JULY 14, 2014), SQUISHY ROBOTS. MIT News. http://news.mit.edu/2014/squishy-robots-0714 (April 12, 2017).

LANIER, J. (2011), You Are Not a Gadget: A Manifesto (Reprint Edition). Vintage, New York.

MAX, D. T. (May 16, 2016), A Whole New Ball Game. The New Yorker. http://www.newyorker.com/magazine/2016/05/16/sphero-teaches-kids-to-code.

MCCRACKEN, H. (August 15, 2013), Sphero 2.0 Is a More Heroic Robotic Ball. Time.

OPLINGER, J. (2011), Orbotix Sphero. The Verge. https://www.theverge.com/products/sphero/4411 (February 7, 2014).

ORBOTIX (2014), Sphero App Update Based On Your Feedback (Press release). Orbotix (February 7, 2014).

ROBOT COMPANIONS (2017), Robot College. http://www.robots-and-androids.com/robot-companions.html (February 20, 2017).

ROBOTIC-FISH.NET (2017), The Website Dedicated to Robotic Fish. http://www.robotic-fish.net/ (April 22, 2017).

ROSENBERG, L. B. (1993), Virtual Fixtures: Perceptual Overlays for Telerobotic Manipulation. In: Proc. of the IEEE Annual Int. Symposium on Virtual Reality (1993), 76-82.

SAVITZ, E. (January 9, 2013), CES: Hey, Sphero! Shall We Play A Game? Forbes.

SPRK WEBPAGE (2017), Program Sphero Robots Using Oval; a C-Based Language. Oval Language. http://sprk.docsapp.io/docs/get-started (February 27, 2017).

STARK, C. (August 30, 2012), Robotic Ball Sphero Rolls Gaming to a Whole New Level. Mashable.

VINCENT, J. (July 19, 2016), This Drone Can Detect and Detonate Land Mines. The Verge. http://www.theverge.com/2016/7/19/12222104/landmine-detecting-drone-mine-kafon-drone.

WESTORT, C. (2003), Robo-dozing. Limits of Landscape: Culture and Technology Conference, sponsored by the Landscape Architecture Foundation and the University of Virginia, School of Architecture, Charlottesville, VA [organized with Elizabeth Meyer, Julie Bargmann, and Nicholas de Monchaux].

WESTORT, C. (2015), Designing Digital Topography: Opportunities for Greater Efficiency with a Primitives and Operators Approach. In: Proceedings 2015 Conference on Autonomous and Robotic Construction of Infrastructure (CARCI 2015), Iowa State University of Science and Technology, June 2-3, 2015, Ames, IA. http://www.ceer.iastate.edu/CARCI/Index.cfm.

WHITE, D. J., JAHRENT, C., VENNAPUSA, P., WESTORT, C., ALHASAN, A., TURKAN, Y., GUO, F., HANNON, J., SULBARAN, T. & DUBREE, A. (2015), Use of the Automated Machine Guidance (AMG) within the Transportation Industry. NCHRP 10-77 Draft Final Report, National Cooperative Highway Research Program, Washington, D.C.

WIKIPEDIA, Sphero. https://en.wikipedia.org/wiki/Sphero.

http://bigthink.com/humanizing-technology/humanizing-technology

http://www.cevinius.com/2015/08/14/making-sphero-into-a-robot-companion/

https://www.hackster.io/michstmatt/sphero-pilot-62f1be