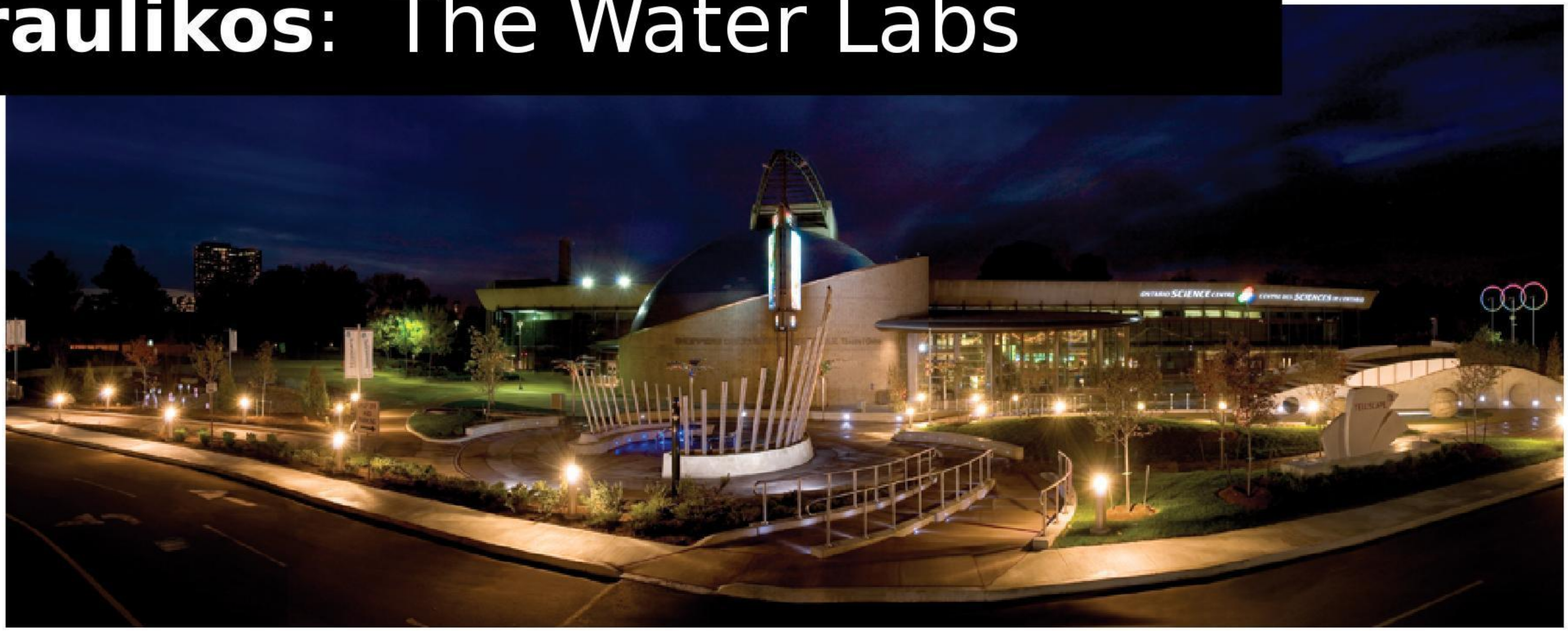
Hydraulikos Urban Water Innovation Laboratory

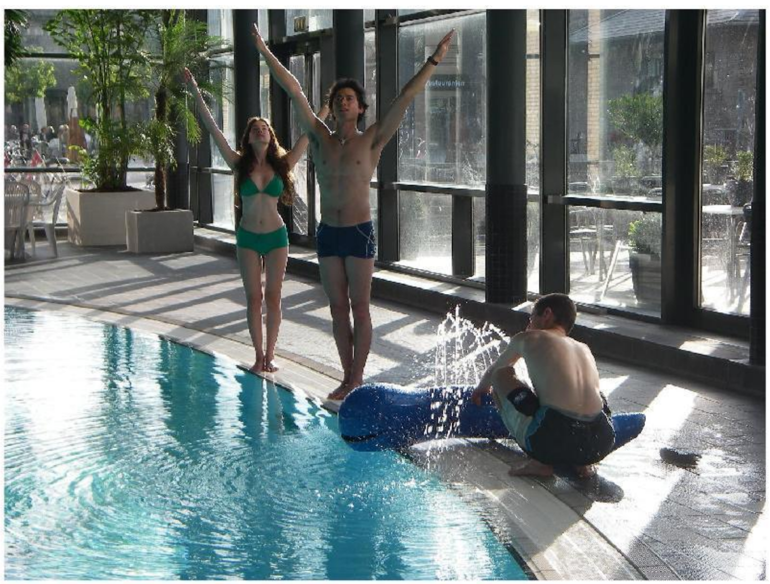
Proposal for a "**Collaboratory**" between
University of Toronto, Waterfront Toronto, ...
to spread to other Ontario waterfront entities. 2011/11/22

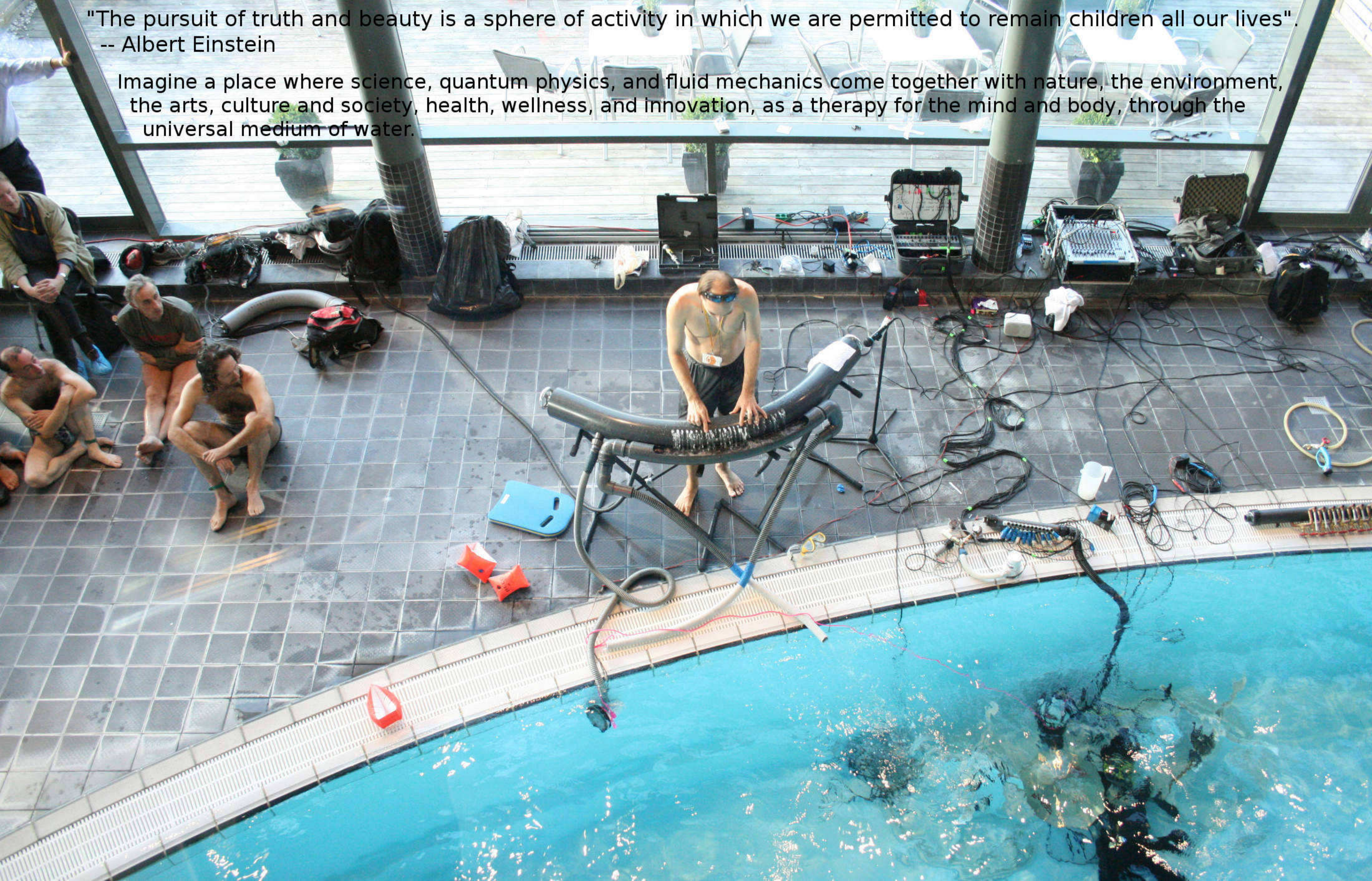
Hydraulikos: The Water Labs



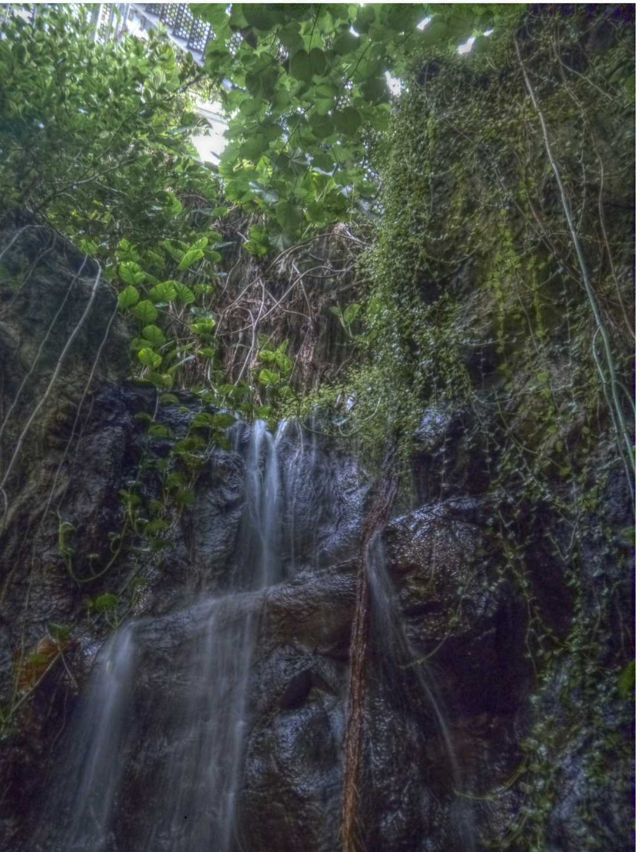
Visions for the **world epicentre of water research**

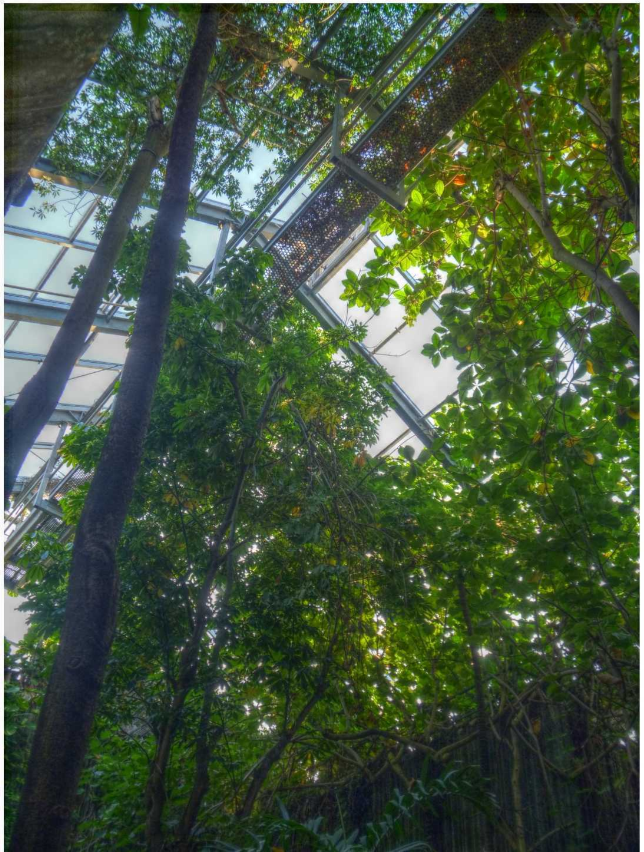
—— science, innovation, arts, culture, mathematics, music, design

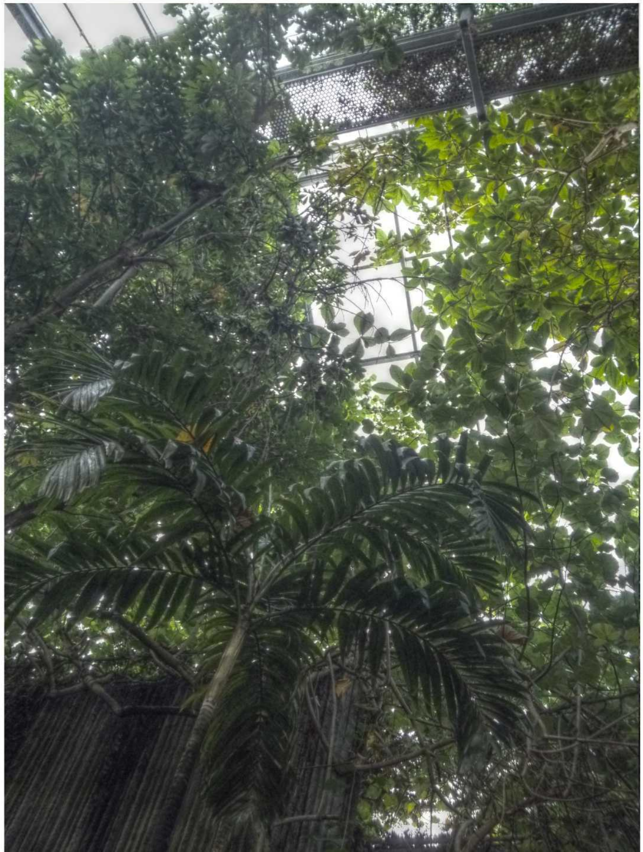



"The pursuit of truth and beauty is a sphere of activity in which we are permitted to remain children all our lives".
-- Albert Einstein
Imagine a place where science, quantum physics, and fluid mechanics come together with nature, the environment, the arts, culture and society, health, wellness, and innovation, as a therapy for the mind and body, through the universal medium of water.


FUNtain.ca

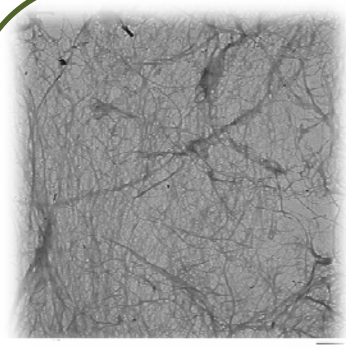






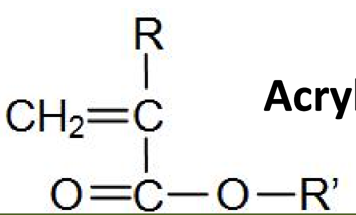
Applications of Nanocellulose from Wheat Straw

Chemo-Mechanical Defibrillation



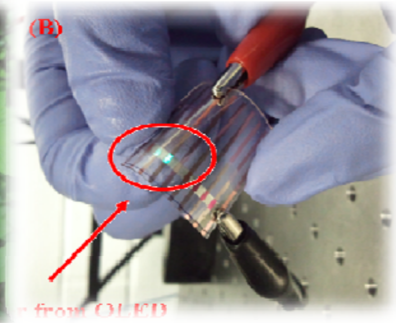
Nanofibres (ø 10-25nm)

+

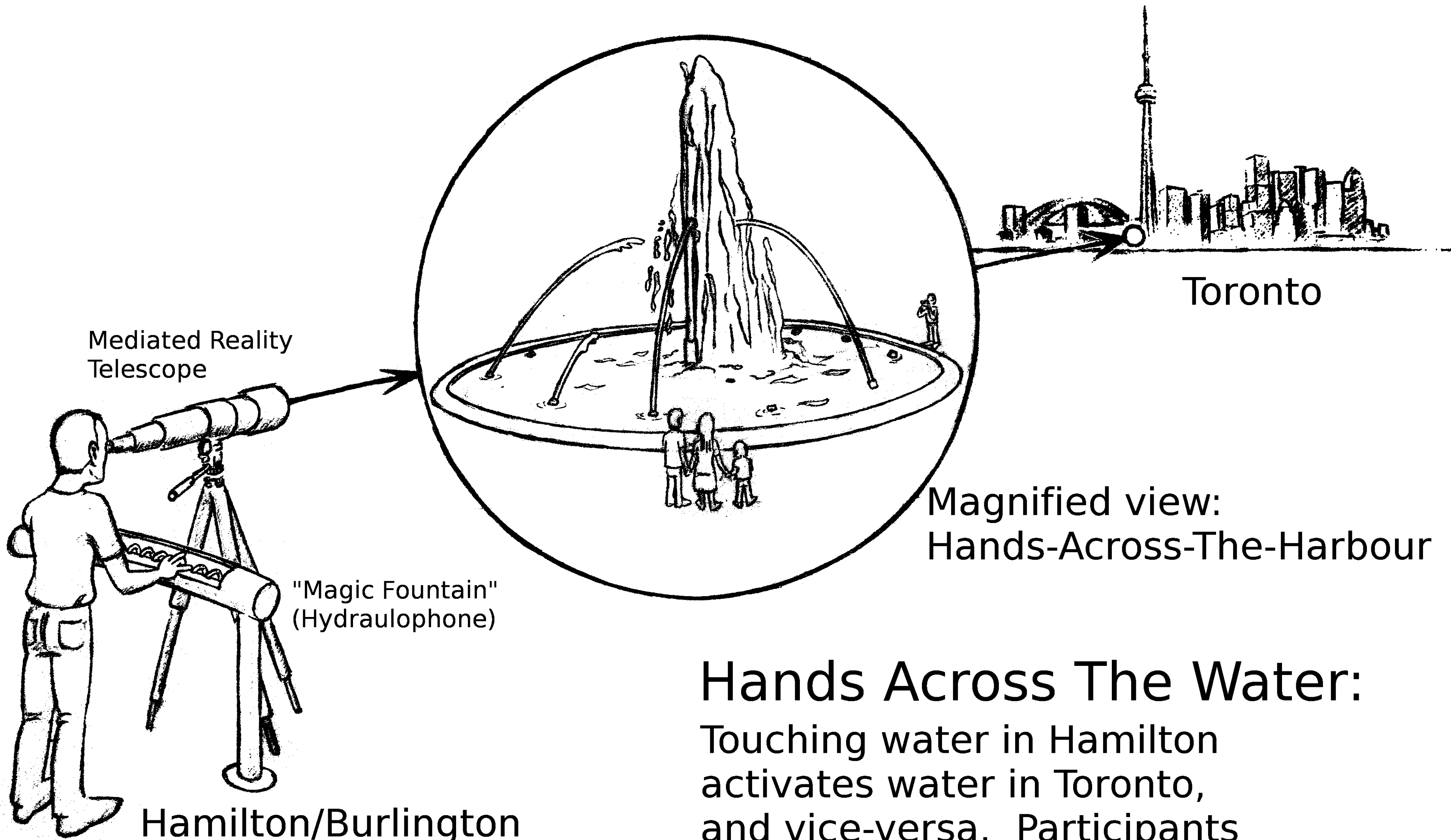


Acrylates

OLED



Hydraulikos



Hands Across The Water:

Touching water in Hamilton activates water in Toronto, and vice-versa. Participants can touch and be touched through the medium of water.

Cross-disciplinary meeting, Tuesday 2011 November 22

Hydraulikos Meeting Agenda, Overview, and Purpose of Meeting

The purpose of this meeting is to identify and advance the goals of the “Water Labs”, and to create a “strong sense of we”, i.e. to contextualize the strategic planning as an exercise in building a common vision. The Water Labs will be cross-discipinary, like the world-famous MIT Media Lab, but with a focus on water and the environment, and with a distributed base of operations (i.e. “Labs” rather than just “Lab”) throughout Ontario and the Great Lakes watershed.

As a temporary working name, we refer to the Water Labs as “Hydraulikos”.

In the meeting we will:

- present a prelimiary version of the Hydraulikos research and development lab where prototyping for the eventual construction of Hydraulikos will take place;
- present working prototypes of some of the items being developed for Hydraulikos, along with an historical framework (ICMC2007, SPLASH2011, etc.);
- identify fundable goals, milestones, deliverables, objectives, ideals, ideas, concepts, and funding sources for Hydraulikos;
- present the 3 phases of the Hydraulikos plan:
    a. research and development of the things to go in Hydraulikos,
        i. funding for the Hydraulikos research and development lab;
        ii. funding for staff person to do R&D lab admin + advancement for R&D lab and for the Hydraulikos deployment;
    b. construction of the first node to begin 4-5 years from now;
    c. construction of additional nodes, e.g. reaching out to other communities and building various cross-disciplinary Water Labs that are all interconnected by WOIP (Water Over Internet Protocol). We wish to eventually have a ship-based node that will connect the land-based Hydraulikos nodes both symbolically as well as physically (e.g. Great Lakes field-trips, collecting and transporting water samples, and bringing people in direct physical contact with lakewater and lake-related research, outreach, and teaching.
- identify collaborators and stakeholders and users of Hydraulikos, and the kind of research that will be done for the creation of Hydraulikos and that will be done in Hydraulikos once it is created.

Here are some of our collaborators, Principal Investigators, and Co-Investigators on existing research grants or proposed grants to be written in the near future:

- Annabel Slaight, Founder and President of Ladies of the Lake and Chair, Committee to Establish a Water Centre for Innovation, Research and Learning on Lake Simcoe
- Sandy Smith (Dean, Faculty of Forestry), Forest Entomolology in Hydraulikos;
- Mohini M. Sain and Sanchita Bandyopadhyay-Ghosh, Centre for Biocomposites and

Biomaterials Processing, Nessonators (Hydraulic resonators);
- Ingrid Stefanovic, Water Policy and philosophy, etc. (SSHRC grant with S. Mann);
- Christina Amon (Dean, Faculty of Applied Science and Engineering), Fluid Mechanics;
- Joseph Orozco, Urban Agriculture (Hydraulikos for sustainable food production);
- Lee Bartel (Faculty of Music), Pedagogies in Music Therapy;
- Norbert Palej (Faculty of Music), Musical compositions for hydraulophone.
- Andrew Francis, a producer and civic strategist who's also the Director of LOLA, the multidisciplinary music/art/digital event.

Hydraulikos Goals and Mission Statement: Centre for Cyborg-Environmental Interaction and Natural User Interfaces

Technology has put us out-of-touch with nature. Our kids are growing up on computer games with Nature Deficit Disorder!
Hydraulikos aims to reconnect us with nature through the medium we all know, love, and trust ---- technology.

My personal narrative as the "aquaborg" or "cyborg-in-the-rainforest" began in my early childhood, with my grandfather, a beekeeper who'd also built greenhouses on his property to grow tomatoes. He taught me how to build wind turbines and solar collectors in early childhood. As a childhood "cyborg" (wearable technologies, etc.) growing up in nature, I bring a unique understanding to "hawlics", the world of HAWL (Humans, Air, Water, and Light).

I invent, design, and build vision technologies (electric seeing aids, www.eyetap.org). One of the best seeing aids is simply the removal of shoes, to be able to connect with the world around us (no longer tripping and falling when equipped with the ability to sense the ground beneath my feet). But in trying to "see with my feet" I'm constantly stopped by police and harassed by security guards and I recently even received a written notice from my child care establishment, that shoes are required in "their" building when dropping off or picking up my children.

When people are discouraged from ---- and even forbidden from ---- a healthy connection with nature, we have a serious problem that goes far beyond technology ---- it reaches into all facets of society. We've all become cyborgs, so much so, that we're forbidden from not being cyborgs. **The goal of Hydraulikos is to allow us to touch and be touched by the most natural of all elements ---- water**, and to invent, develop, research, and teach technologies that facilitate a connection with our natural world.

Hydraulikos: The Water Labs

"The pursuit of truth and beauty is a sphere of activity in which we are permitted to remain children all our lives".
-- Albert Einstein

The Water Labs will be cross-discipinary, like the world-famous MIT Media Lab, but with a focus on water and the environment, and with a distributed base of operations (i.e. “Labs” rather than just “Lab”) throughout Ontario and the Great Lakes watershed. We refer to the Lab(s) as “Hydraulikos”, the place or places (distributed place) both physical and virtual.

Hydraulikos will be a place where science, quantum physics, and fluid mechanics come together with nature, the environment, the arts, culture and society, health, wellness, and innovation, as a therapy for the mind and body ---- where music meets math, and the compartmentalized silos of academia are washed away with lateral thinking. And where the boundary between work and play can also dissolve, for those who wish to engage in the existential epistemology of a medium that's at once broad and deep ==== water.

Hydraulikos: Water-based Art, Science, and Innovation.

The Water Labs aims to be a place that has the depth of a PhD degree-granting institution, combined with the breadth of our most iconic cultural venues. Imagine you could remain a child your entire life, and discover the ineffable sense of awe and wonder a child does at the Science Centre, while conducting world-class research.

Places like Art Gallery of Ontario (AGO) are about art, and art asks questions at a deeper level which doesn't happen at a science museum. But the science museum allows you to touch things and play with them.

We envision research and practice that asks the deep questions art does, while being hands-on, tangible, touchable, inventive, and bridging the boundary between professionalism (work) and play.

Those 3 things:

1. art,
2. science, and
3. technology (invention, patent worthiness, and innovation)

have never been brought together in a single world-class centre.

Water packets (WOIP = Water Over Internet Protocol).

One idea that popped into my head is to create an Ontario-wide sculpture in which water packets shoot across the Lake Ontario, Lake Simcoe, Lake Erie, etc., watersheds.

The use of water packets as data packets is something I've explored at length (sending water and human touch across the Internet). We as humans share one water, and water is the one thing that connects us. This project would also connect with Toronto's innovative new waterfront, said by some to be the most Internet-connected place in the world.

Ontario as water capital of the world.

Our Great Lakes are the world's largest freshwater surface with more than 80% of North America's fresh water (more than 20% of the world's supply of fresh water). The Great Lakes are spread across eight states to the South, but are wholly contained in a single province to the North: Ontario! Whereas it will take many years before the eight states to the South reach a consensus, the Ontario Ministry of the Environment has announced its intention that Ontario be recognized as North America,s epicenter of clean water.

Whereas artistic and cultural discourse of the last millennium was focused on oil ("blood for oil" etc.) this millennium concerns itself with water as the world's most important natural resource, as the world runs dry and water conservation is of the utmost importance.

Thus if water is "the new oil" then Ontario is "the new Saudi Arabia", so it seems natural that the world's "Water Centre" would be located in Ontario.

I've been collaborating with groups like Ladies of the Lake (Lake Simcoe), Ontario Science Centre, Royal Ontario Museum (as part of the Water Exhibit), as well as other water-related centres all over the world. I'm also collaborating with EBW (Evergreen Brickworks) and am in discussions with Waterfront Toronto as well as the owner of Ripleys regarding Canada's Aquarium being built at the base of the CN Tower.

One possible scientific and artistic vision would be to produce a series of sculptures throughout Ontario's watersheds, that are linked together using water packets, "WOIP" (water-through-the-Internet, packets) in conjunction with the Toronto Waterfront's vision of the world's fastest internet communities. For example, something that could also be connected to the Don River Park waterplay area that's opening in 2012.

Why Ontario should be water capital of the world....

- Ontario is the world's epicenter of water (see above).
- Ontario is where the hydraulophone was invented[1][2][3]
    - Invention of the hydraulophone marks the first time in human history that anybody has made a musical instrument that makes sound from vibrating water itself
    - This is the first time in human history that water has been given a "voice"

    - Previous instruments, e.g. strings percussion and wind; strings and percussion both make sound from vibrating solid matter, wind from vibrating gas, but before, there was no instrument from vibrating liquid itself.
- Dundas Square is something I call an urban beach[4]
    - It is analogous to Times Square in New York.
    - Times Square is said to be "the world's stage" or in many ways at least an epicenter of the US.
    - In this same way, Dundas Square is a civic and cultural epicenter of Canada.
    - That Canada's civic and cultural "Times Square" type epicenter is a waterpark is no accident; I've written published articles on this space extensively[4][5].
    - Dundas Square is located in Ontario.
- Hydraulophones have been installed all over the world, Legoland California, Chicago Children's Museum, Baylor Museum in Texas, in Egypt, Austria, Australia, and Canada, etc.....
- But the world's biggest hydraulophone is right here in Ontario, specifically at the Ontario Science Centre.
- The OSC hydraulophone is a centerpiece of one of the world's few 24 hour-a-day waterparks, freely accessible to everyone.
- This waterpark is designed to symbolize water, e.g. the walkways are made in the form of dried riverbeds, etc., and it includes many futuristic environmentally forward-thinking technologies.
- Toronto Harbourfront is an important cultural and civic area.
- WATERFRONToronto, (Toronto Waterfront) is being designed as the world's most technologically advanced waterfront. One feature is Internet connectivity that is 500 to 1000 times faster than elsewhere in North America.
- This includes developments for the Pan Am Games 2015 along the waterfront.
- Evergreen Brickworks, one of the world's most forward-looking environmental organizations, and the Don Valley are connected in this watershed.
- Evergreen Brickworks is also located in Ontario.
- Ontario will soon be home of “Canada’s Aquarium” being built near the base of the CN Tower.
- Ontario is home of the world's first Blue Roof, which won first prize of 10,000 euros, in the Coram Sustainable Design Award, http://www.coramdesignaward.nl/php/ceremonies.php?ID=6
- Blue roofs revolutionize sustainable development by using water to cool solar panels and make them run more efficiently and rainwater collected off solar panels is clean due to the relatively sterile nature of the glass, thus resulting in more efficient energy and water usage, capture of as much rainwater as needed for the building's water supply plus leftovers go to irrigating the greenroof that is part of the blueroof concept.

Hydraulikos in the short-term and the long-term.

Hydraulikos could be built in two stages. The first stage would be find a temporary home for the many experimental setups, apparatus, exhibits, and teaching tools already developed for Hydraulikos. This could be a place as simple as an existing greenhouse, or perhaps a suitably tiled space with a floor drain and large South-facing windows, to provide a space that’s warm and sunny year-round, and where water can be splashed around on a large scale.

The second stage would be to raise awareness, and fun(d)s, to build a more permanent home for Hydraulikos. This could, for example, take the form of a building on the shores of scenic

Lake Simcoe, built in conjunction with the Ladies of the Lake. The basement of the building might have submarine-style portal windows looking right into the lake underwater, with the upper floors cantilevered out over the lake, providing suitable rigging for a variety of experiments, performances, teaching and research setups. The space would contain warm sunny areas in which one could work in a bathing suit with water splashing everywhere in the middle of the Canadian winter, and not feel cold. The space could also have cooler areas where various instrumentation and laboratory equipment, fluid dynamics process control experiments, and the like could be conducted. There would also be research and teaching areas, including an indoor classroom, as well as an outdoor classroom, like the one we helped build for the CNIB (Canadian National Institute for the Blind).

Hydraulikos might also take the form of a research vessel to do "water research on the water". The vessel could bring researchers together and collect water samples is it travels the Great Lakes and Canada's coastal waters.

--Steve Mann, 2011

References

[1] "Fluid Melodies", Steve Mann, Watershapes, Volume 10, Number 2, February 2008, Cover +pp26-45, See www.wearcam.org/watershapes/index.htm

[2] Natural Interfaces for Musical Expression: Physiphones and a physics-based organology, NIME 2007, pp118-123, also available at: http://www.eyetap.org/papers/docs/mann_physiphones.pdf

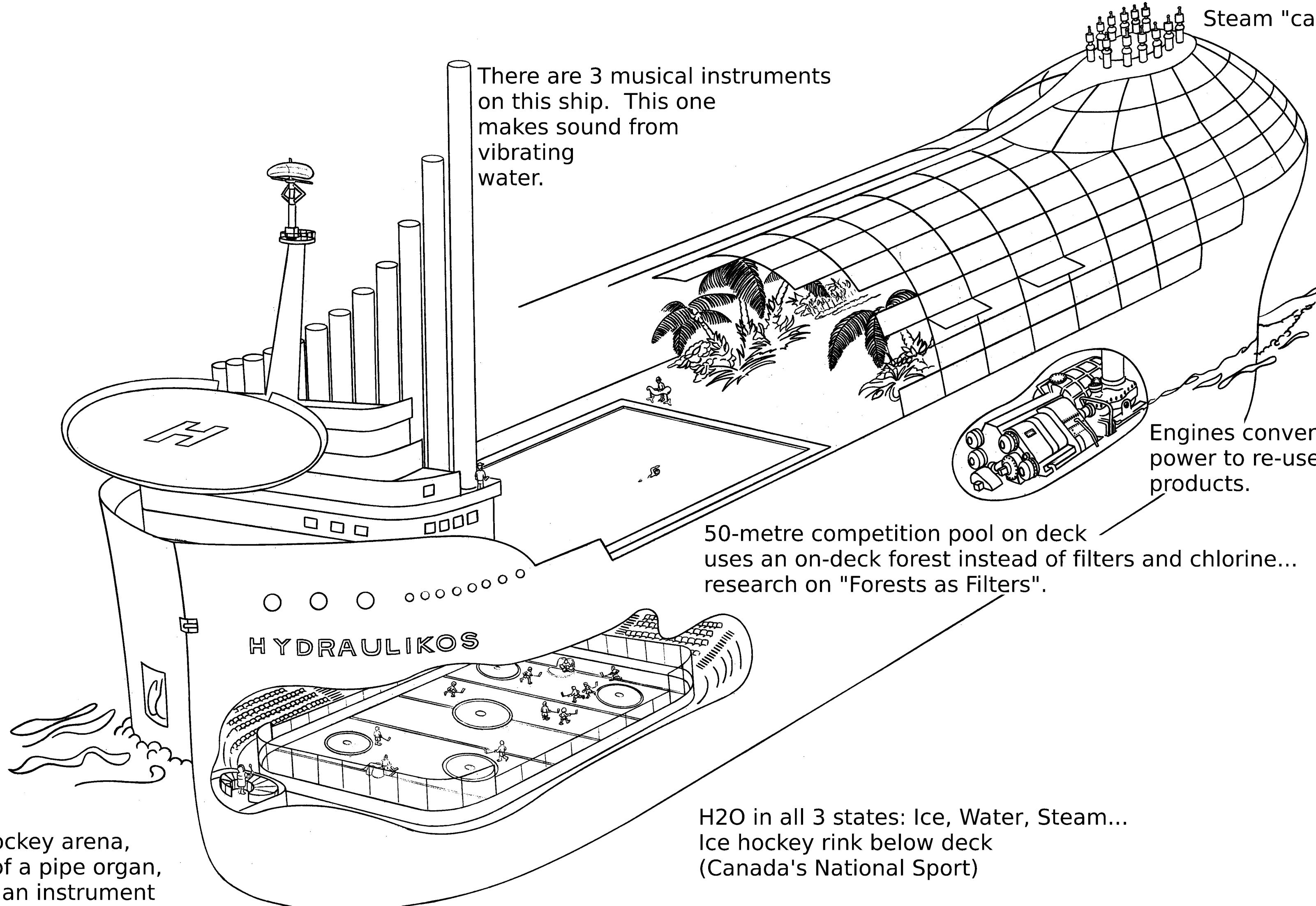
[3] US Patent 8,017,858 "Acoustic, hyperacoustic, or electrically amplified hydraulophones or multimedia interfaces", Steve Mann.

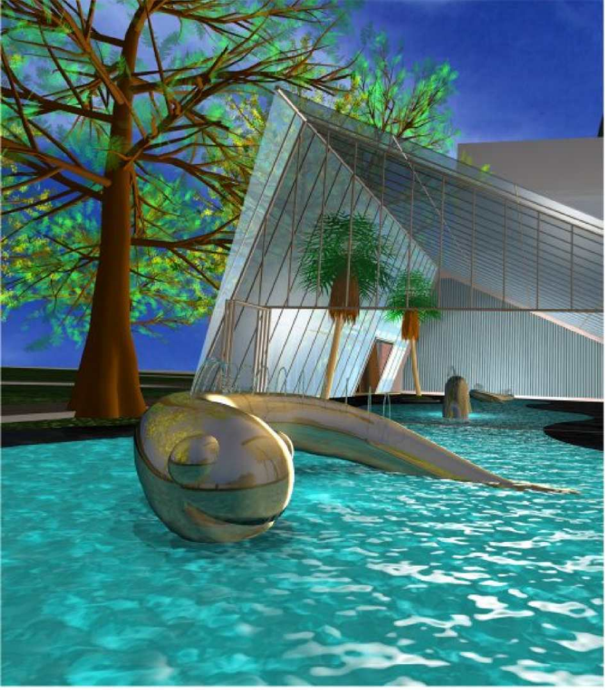
[4] Reading Cities, 2006 12 07, The Urban Beach Meets Steve Mann's Hydraulophone, http://www.readingt.readingcities.com/index.php/toronto/comments/3579/

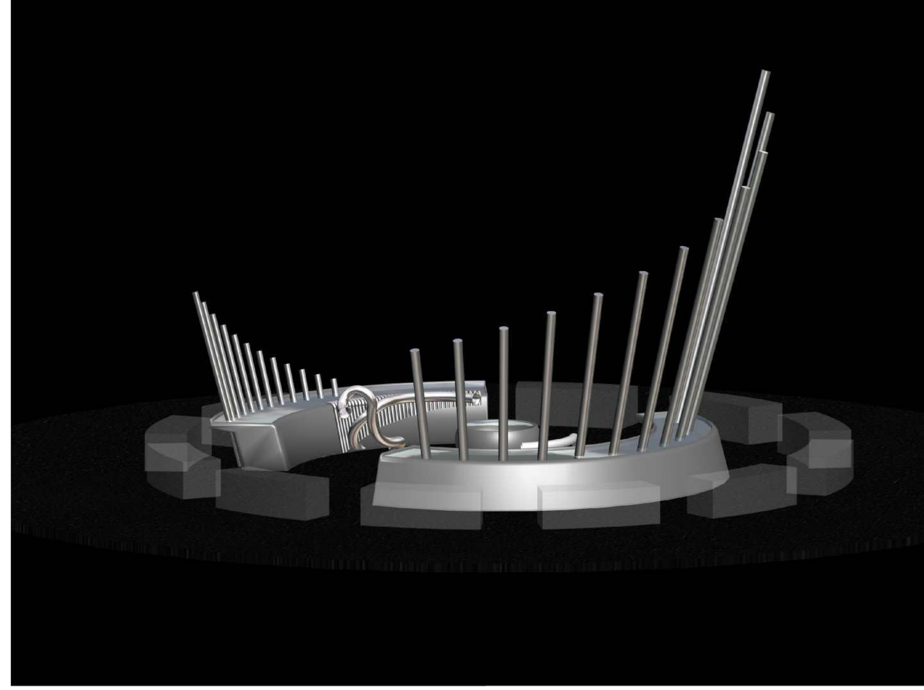
[5] People Watching People Watchers, Steve Mann, Surveillance and Society, 2(4): 594-610.

[6...] Please let me know other references, your own work, or related work by others, that we can add to this bibliography. Presently I've listed my own work, but we want to be inclusive of the work of everyone participating!

Hydraulikos Research Vessel

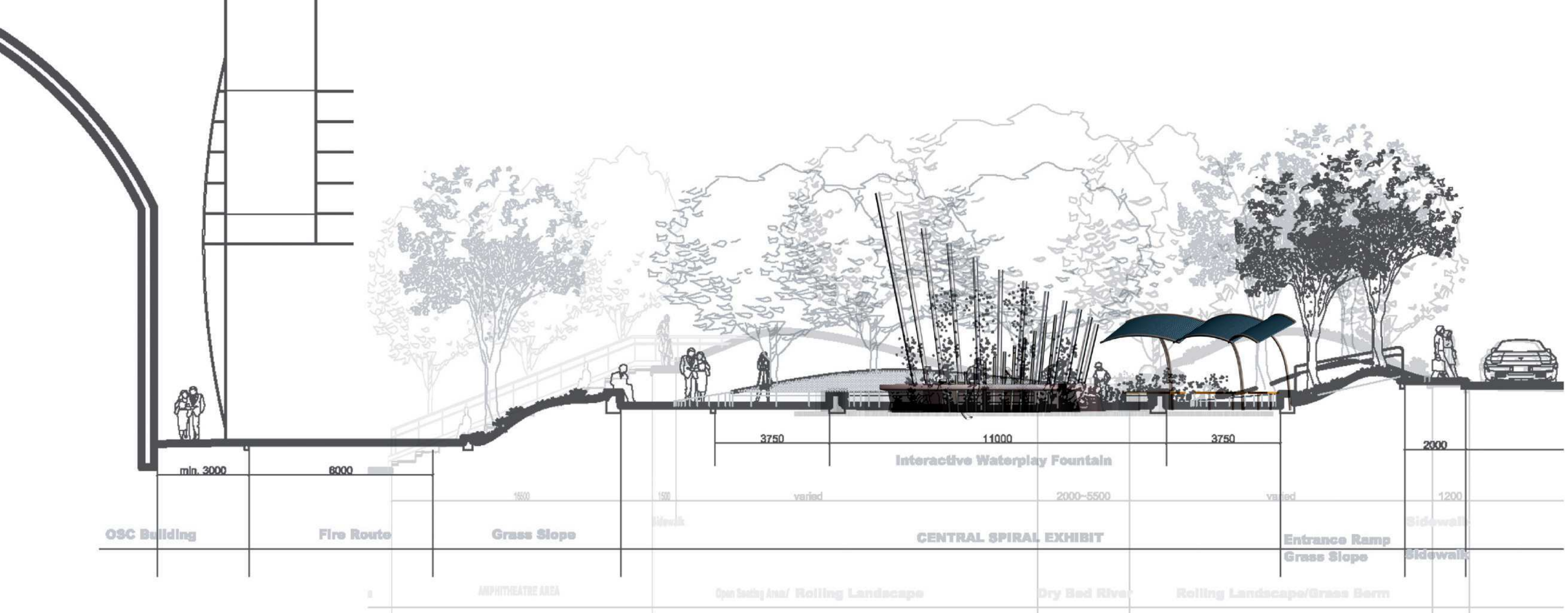






hydraulophone

civic sculptures + musical instruments



This hydraulophone installation, as the main architectural centerpiece out in front of the Ontario Science Centre, is a musical instrument that is open to the public 24 hours a day.

Top: Aerial view of hydraulophone installation in Teluscape park.
Bottom: Nighttime panorama of the piece.

CATHY MCFEE:

CNIB OPENS INNOVATIVE OUTDOOR CLASSROOM FOR CHILDREN

BY **SARAH FABBRI**

A young boy in a playground giggles when he discovers that a special water fountain he is playing with makes different sounds when he moves his fingers – like a keyboard. The boy is blind and he's playing on something called a hydraulophone which is helping him learn more about the world around him. He's in the CNIB's (Canadian National Institute for the Blind) recently opened Outdoor Classroom in Calgary. It's the first facility of its kind in Canada.

"We have created something that has tremendous meaning for these children and their families," says Cathy McFee, Director of Services and Operations, CNIB - Alberta NWT Division. McFee received her Leadership Development Certificate of Excellence last spring and says her Banff Centre experiences played an important role in the development of the Outdoor Classroom.

The idea for the classroom started more than two years ago when employees with Urban Systems, a Calgary consulting firm, participated in the United Way's Day of Caring by painting fences in the CNIB's Family and Children's area, says McFee.

"We invited the Urban Systems team in for a tour, to share information about CNIB, and this led to some discussion about developing a sensory playground to better meet the needs of children with vision loss," she says. Currently CNIB Calgary has about 80 preschool children registered with its services.

"We started to ask ourselves questions such as: Who uses this space? How is it used? How does it compliment the services of the CNIB program?" says Leighton Ginther of Urban Systems.

There was a lot of enthusiasm and creativity, recalls McFee. "We pulled together an exciting plan. We designed an educational facility where children with vision loss could explore, develop skills, and build confidence in a safe, interactive and accessible environment."

Plans featured a tactile map at the entrance to help children mentally map the outdoor space, a looped pathway system to give children the opportunity to develop their orienteering skills, a xylophone, and a sound bench.

"We were faced with a number of challenges," says McFee. These included securing approval from the CNIB's national office and securing the resources to fund the project.

At the time, McFee was just about to start her fourth Leadership Development program, *Leading Teams for High Performance.*

During Leading Teams, McFee says she had a chance to present the Outdoor Classroom plans to her learning group. "I gained more confidence about how to communicate a plan to our national office, highlighting the benefits and outcomes to the organization. I (also) learned about staying focused, connecting with my own sense of values, and leading others with both purpose and passion."

The national office gave McFee the nod of approval to go ahead with the project.

McFee and her project team then secured additional partners in addition to Urban Systems, including WestJet. The tasks expanded, from creating a fundraising strategy to organizing volunteers.

"I learned about facilitating a new team that involved both internal and external stakeholders," explains McFee. She now had to build consensus and foster collaboration around a common goal.

In November 2007, McFee took *Art of the Executive Leader,* her fifth program. "One of the things I have learned is that for nonprofit organizations to be competitive and successful you need to be innovative and mobilize every sector of society."

On October 3, 2008 McFee's shared vision became a reality and the CNIB Outdoor Classroom officially opened. The most memorable moment for McFee was watching several of the young children with vision loss engaged in play with the many components of the Outdoor Classroom.

"One very small child stood quietly – head bowed, eyes closed, tiny hands grasping onto the smooth xylophone bars – enjoying the calming vibrations of sound as his father delicately struck the instrument," McFee says.

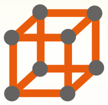
McFee says she is grateful for the support she has received along her 10-year learning journey, one made possible thanks to the generosity of others. "It happened because of the Centre's scholarships for non-profit leaders and I want to express my gratitude and appreciation."

Sarah Fabbri is marketing officer for Leadership Development.

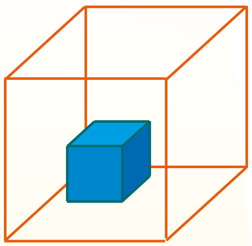
Physics-based Musical Instrument Classification

THE FIVE ELEMENTS OF MUSICAL INSTRUMENTATION

1 SOLID "Earth"



strong bonds

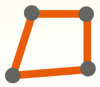


holds shape
fixed volume

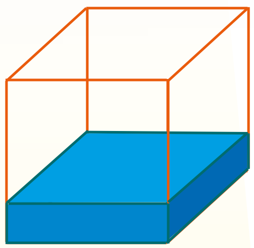
GAIAPHONES "Solid Instruments"

1.1 chordophones
1.2 membranophones
1.3 idiophones

2 LIQUID "Water"



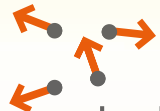
weak bonds



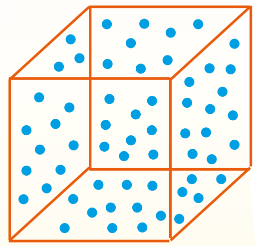
shape matches bottom of container, flat surface above
fixed volume

HYDRAULOPHONES "Water Instruments"

3 GAS "Air"



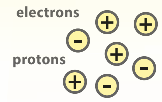
no bonds



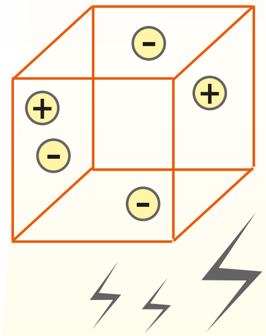
shape matches container
fills volume of container

AEROPHONES "Wind Instruments"

4 PLASMA "Fire"



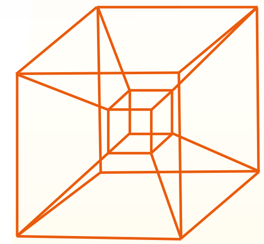
ionization



PLASMAPHONES "Plasma Instruments"

5 QUINTESSANCE "Idea"

Process or procedure not limited by matter



hyperspace, not limited by space constraints

QUINTEPHONES "Non-physical Instruments"

- mechanophones (mechanical comp.)
- electrophones
- optiphones (optical computing)
- biological computing
- neural networks


The hydraulophone is a musical instrument used around the world in concerts and dramatic performances to raise awareness of the importance of clean lakes, rivers, and water as a natural resource.
Each water jet is a key on this water keyboard. Sound from vibrating water makes intricate microtonal harmonizations

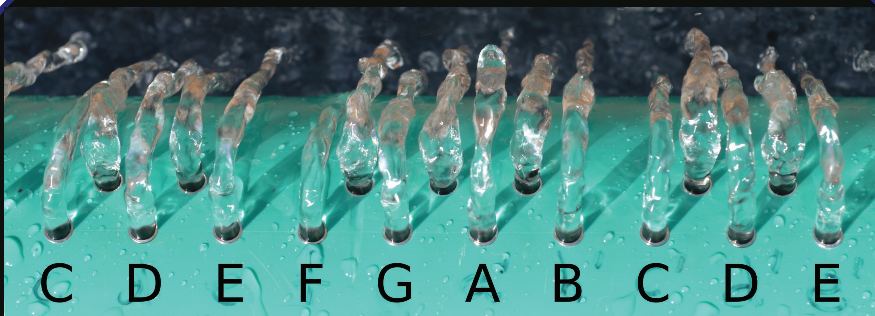
H2Orchestra was the main act for SPLASH Festival 2011.
Lake Simcoe was turned into the world's largest musical instrument.
Turning the lake itself into a giant musical instrument raised
awareness of the importance of clean lakes and rivers.

Polyphonic Embouchure

on an Intricately Expressive Waterflute formed by an Array of Water Jets

Steve Mann · Ryan Janzen
University of Toronto

NSERC CRSNG
Ontario Centres of Excellence — Where Next Happens
University of Toronto — Faculty of Applied Science & Engineering

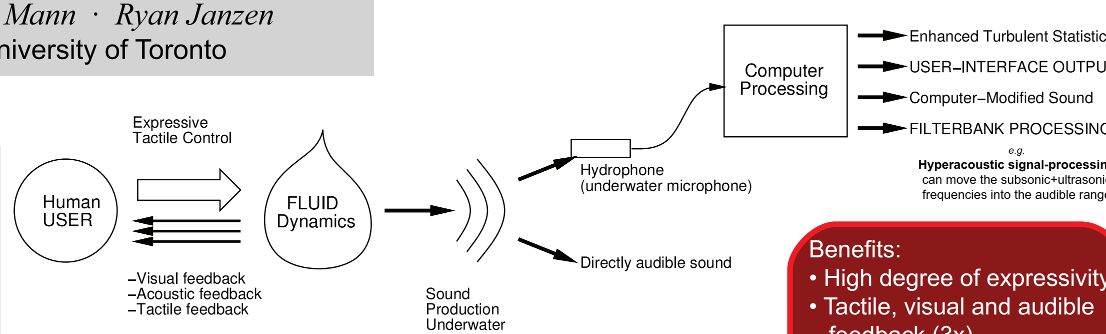


Hydraulophone: A Newly-invented musical instrument

- Uses WATER as sounding mechanism
- Unlike previous instruments that used water merely as a source of pressure to drive air through sounding pipes, the hydraulophone is the world's first instrument that has been able to produce sound *purely from vibrations in water itself, without requiring any air to vibrate whatsoever.*

- Turbulence from fluid-dynamics
- Finger touches water to control
- Fluidly-continuous control over multiple water flows, independently for each finger.

- Concert hydraulophones —► performance in the concert hall
- Acoustic hydraulophones can be affixed with **hydrophones** (underwater microphones) to pick up the underwater sound
- Can be used as a **user-interface** to control other systems (via computational processing of the sound)



Benefits:

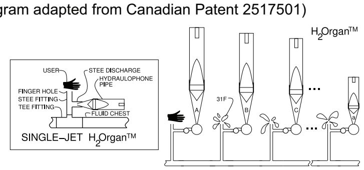
- High degree of expressivity
- Tactile, visual and audible feedback (3x)
- Close coupling between finger, user-interface, and medium of sound-production

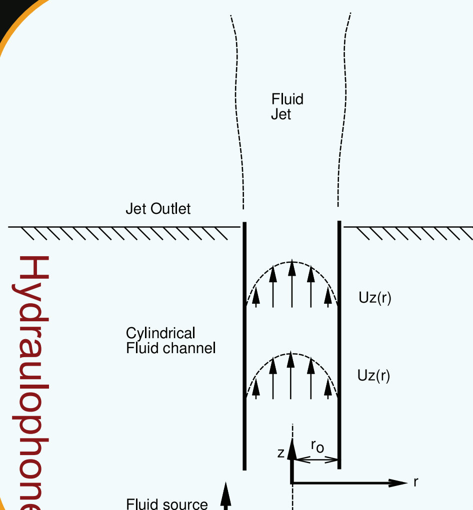
Rich expressivity in 5+ Dimensions

- x, y, z, A_c —► time-varying pathway of motion through water flow
- 45 independent jets (or 12)
- Sensitive also to derivatives and integrals of displacement: dx/dt, d^2x/dt^2, d^3x/dt^3, ... plus integrals.

- **Sound produced directly by the fluid**
- Subsonic, audible, and ultrasonic frequencies
- Human finger affects the sound by freely rocking against the turbulent flow

Example of sounding chamber: Underwater organ pipe.
Block a jet —► Water diverted into sounding chamber
Free a jet —► Bernoulli principle —► small vacuum drawn on the side-discharge pipe, to silence the corresponding sound.
(Diagram adapted from Canadian Patent 2517501)





Poiseuille Parabolic Flow Profile

- Velocity and Momentum profiles are arranged to provide nonlinear expressive touch control
- Hydraulic bond between finger and turbulent water: allows richly expressive control

Velocity as a function of position:

$$\vec{\mathbf{u}}(\vec{\mathbf{r}}) = u_X(\vec{\mathbf{r}})\cdot\hat{\mathbf{x}} + u_Y(\vec{\mathbf{r}})\cdot\hat{\mathbf{y}} + u_Z(\vec{\mathbf{r}})\cdot\hat{\mathbf{z}}$$

$$\text{with } \vec{\mathbf{r}} = r\cdot\hat{\mathbf{R}} + \theta\cdot\hat{\boldsymbol{\theta}} + z\cdot\hat{\mathbf{z}}$$

$$\text{In this case: } \vec{\mathbf{u}}(\vec{\mathbf{r}}) = \vec{\mathbf{u}}(r), \quad u_X(r) = u_Y(r) = 0$$

$$u_Z(r) = 2\left[1-\left(\frac{r}{r_O}\right)^2\right]\frac{Q}{\pi r_O^2}$$

Q=bulk flow rate
μ=dynamic viscosity
p=pressure

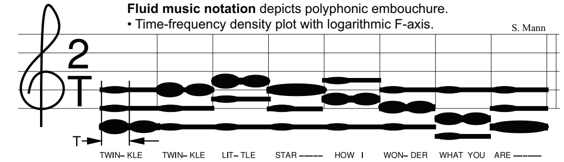
$$u_Z(r) = 4\mu\left(-\frac{\partial p}{\partial z}\right)\left(r_O^2 - r^2\right)$$

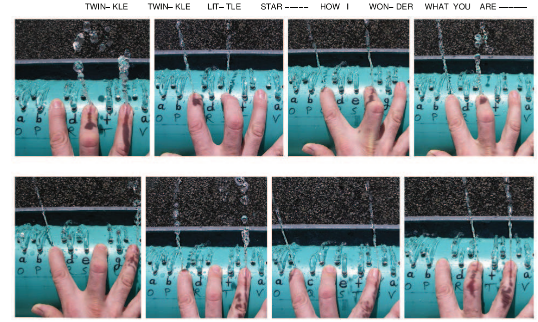
This is merely the quiescent velocity. Disturbing the flow with a finger —► u_z breaks into $u_z(x,y,z)$; nonzero $u_x(x,y,z)$, $u_y(x,y,z)$ —► Flow becomes nonaxial and evolves toward turbulence as the Reynolds number increases

- Turbulent spectra shift and intensify around tuned frequency, in the vicinity of resonant flow structures (water flowing through **sounding chamber)**

POLYPHONIC EMBOUCHURE NOW POSSIBLE

Fluid music notation depicts polyphonic embouchure.
- Time-frequency density plot with logarithmic F-axis.





Polyphonic Embouchure Fingering Technique

First image: C-major chord played with emphasis on the first note of the melody, C (the flow of the C-jet is fully restricted), while the E and G jets are being partially restricted.
Second image: the same three jets are blocked, but the emphasis is shifted fluidly and continuously toward the G jet, without any disruption in the harmony.
This fingering progression is a very simple example illustrating *harmelodic performance technique*, with two phrases of a simple childrens' song: (top) "Twinkle twinkle little star" and (bottom) "How I wonder what you are".

New Compositions - Only playable on Hydraulophone:

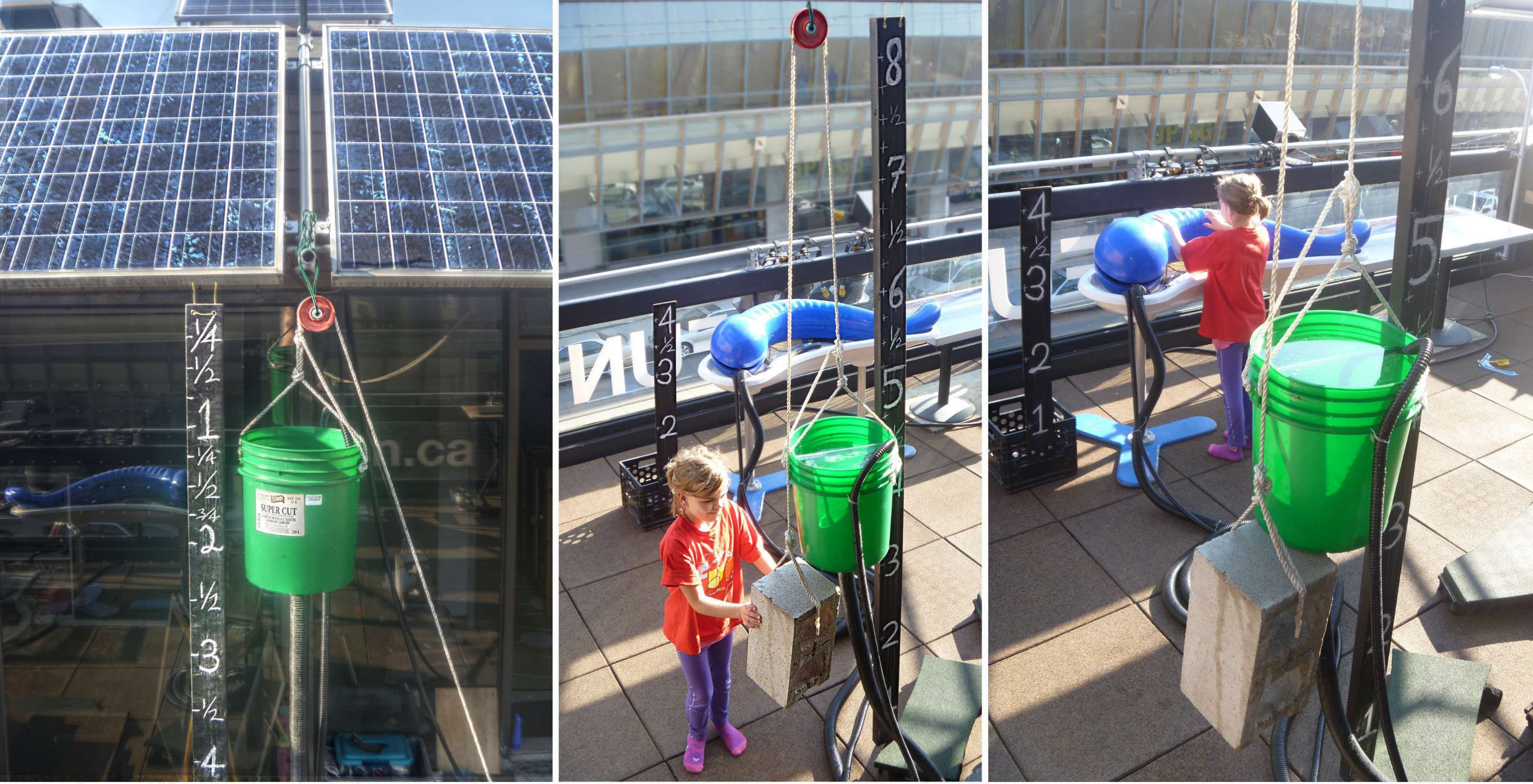
- ***Suite for Hydraulophone and Orchestra***
- ***October Alchemy Beckons***

samples at: ryanjanzen.ca

Steve Mann **wearcam.org** hydraulophone@gmail.com
Ryan Janzen **ryanjanzen.ca** rejanzen@gmail.com

Funtain.ca = spinoff company that manufactures hydraulophones

Acknowledgements to **Chris Aimone** and **David Gildiner** for their contributions



Hydraulikos activities: Science, exploration, experimentation, and understanding

Hydraulikos: The Water Labs at the nexus of science, innovation, arts, culture, sustainability, health, wellness, mathematics, music, fun, and frolic

Steve Mann
University of Toronto
Dept. E.C.E., 10 King's College Rd., Toronto, Ont., M5S 3G4
http://wearcam.org/hydraulikos/

ABSTRACT

Eighty percent of North America's freshwater is in our Great Lakes, in eight states on the US side, and just one provice – Ontario – on Canada's side. Getting eight state governors to agree on anything may take years, but Ontario is committed to being a world epicenter of "all things water".

Hydraulikos is about connecting people with water all across Ontario, in a way that transcends place or discipline. Imagine, for example, a water center having various "nodes" around the Great Lakes and Lake Simcoe, and a giant greenhouse on a steamship, built from a recycled lake freighter, that connects the nodes.

Hydraulikos is a research vessel for oceanography, and lake-related research. But it also is itself a research lab. One aspect of research is forests-as-filters.

Inside the giant greenhouse is a forest with natural swimmable rivers and ponds that connects these various nodes. On deck there is a swimming pool that uses the forest as its filters, and thus supports research on the use of natural ecosystems in harmony with the on-deck olympic competition-size pool that runs off these natural living waters.

Below deck is a hockey rink, completing the cycle of H2O in all three states-of-matter: solid (ice), liquid (water), and gas (steam). The organ in the hockey arena is a pagophone, a musical instrument that makes sound from vibrations in ice.

The water-ship could dock at any harbour and offer wintertime swimming, water-study, school field-trips, and university-level research that travels from shore-to-shore to teach, learn, and educate about water. Hydraulikos thus need not be limited to one geographical location!

This document presents some ideas, inventions, activities, and public art installation concepts aimed at the creation of Hydraulikos, cross-disciplinary Water Labs throughout Ontario.

There currently exist other water centres that focus on specific research agendas, such as the Walkerton Centre for clean drinking water research. Some community centres with pools are referred to as "water centres", but if you try to bring along some experimental apparatus to study fluid mechanics, you may find yourself in an argument with the lifeguards.

There is a need for, and a tremendous opportunity to provide, a world epicentre for research on all aspects of water because the very nature of water is primal, universal, and at once both broad and deep.

Hydraulikos activities might include scientific studies of water flow, research, teaching, demonstration, and outreach, perhaps, for example, an underwater musical concert arising from a study of HagenPoiseuille flow and NavierStokes equations of obstructions in flow channels, along with new inventions and innovations for a greener planet and cleaner lakes.

The Centre will not just be for university students and professors. It will also embody community outreach and thus help people of all ages, including those with special needs. The goal is that Hydraulikos would bring together science, ecology, water quality research, freshwater and ocean ecosystems, innovation, arts and culture, health and wellness, music, fun, and frolic in a crossdisciplinary, transdisciplinary, and even undisciplinary (i.e. to encourage unstructured play) manner.

This document describes some personal experiments and experiences on the shores of natural lakes and rivers, and other bodies of water, as well as first steps toward the eventual creation of a "frolic lab" and "teach beach" at each node of the water labs, in which water is presented and explored as a tangible interactive natural user interface.

Author Keywords

Interactive Art (primary keyword) Input / Interaction; Interface / Experience Design; Hardware (e.g., sensors, actuators, displays); Auditory / Sound Interfaces; Gestural / Perceptual / Vision-based Interfaces; Children / Education; Haptic/ Force Feedback; Art / Music

DECONference 2011, November 22, 2011, Toronto, Ontario, Canada.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Miscellaneous—*Optional sub-category*

General Terms
Measurement, Performance, Design, Experimentation, Human Factors

HYDRAULIKOS, ETYMOLOGY
Hydraulics broadly refers to all situations in which water flows, is moved, or is manipulated in some way.

The word "hydraulics" originates from the Greek word "hydraulikos" which means water instrument (from the Greek words, "hydor" for water and "aulos" meaning musical instrument or hollow tube).

The field of hydraulics originated with music, because the first application of hydraulics was when the ancient Greeks and Romans used water as a source of power to compress air into their pipe organs (the early Greek and Roman wind instrument, the Water Organ or Hydraulis [1][3]).

CYBORG IN THE RAINFOREST: HUMAN-ENVIRONMENTAL INTERACTION AND NATURAL USER INTERFACES
Technology has put us out-of-touch with nature. Our kids are growing up on computer games with Nature Deficit Disorder!

Hydraulikos aims to reconnect us with nature through the medium we all know, love, and trust —- technology.

My personal narrative: I've often been described in the mainstream media as well as various research publications as "the world's first cyborg", and as the "father of wearable computing". Since my early childhood I've melded my mind and body with various machines and invented many different kinds of "cyborg" technologies from computational seeing aids (www.eyetap.org) to brain-computer interfaces.

At the same time, I've had a love of nature and all things natural. This began in my early childhood, with my grandfather, a beekeeper who'd also built greenhouses on his property to grow tomatoes. He taught me how to build wind turbines and solar collectors in my early childhood.

Thus I see as an important goal of Hydraulikos, the study of the relationship between technology and nature! For example, although I invent, design, and build vision technologies (electric seeing aids, www.eyetap.org), one of the best seeing aids is simply the removal of shoes. This enables a person to connect with their immediate environment, be it the earth, the floor, or the steps on a stairway (no longer tripping and falling when equipped with the ability to sense the ground beneath one's feet). But in trying to "see with my feet" I'm constantly stopped by police and harassed by security guards and I recently even received a written notice from my child care establishment, that shoes are required in "their" building when dropping off or picking up my children. When people are discouraged from —- and even forbidden from —- a healthy connection with nature, we have a serious problem that goes far beyond technology —- it reaches into all facets of society. Interestingly a blind graduate of Liberty University in Texas, who goes barefoot everywhere, had to get a doctor's prescription and use the ADA (American's with Disabilities Act) to counteract harrassment by security guards.

With technologies like shoes, we've all become cyborgs, so much so, that we're even forbidden from not being cyborgs. My way of dealing with rules against being barefoot was to invent "smart shoes" with pressure sensors, miniature ground-watching cameras, and wearable computing technology to create new ways of feeling and mapping the ground or floor.

Thus Hydraulikos will facilitate research on Human-Environment Interaction. By "Human-Environment Interaction" I mean it in a broader sense than geographers often use it, i.e. I also mean it in the way that we use the term "Human-Computer Interaction", i.e. to include how a human interacts with their immediate environment (e.g. stairs or carpet), whether natural or not.

Like the Outdoor Classroom I worked on for the CNIB's (Canadian National Institute for the Blind's) Calgary headquarters, I want to see Hydraulikos facilitate our research in technologies that help people —- technologies like computerized eyeglasses that work in all weather conditions, including the rainforest of Hydraulikos. Or understanding how we walk, in a controlled simulation of a natural rainforest environment.

Hydraulikos will be used to study nature, as well as to mimic nature. For example, I invented a kind of computer user-interface which is based on interacting with natural objects in the environment, rather than artificial control devices like the mouse and keyboard. Using nature and natural elements (Earth, Water, Air, etc.) as computer user interfaces is another area of research we wish to explore in Hydraulikos. These Natural User Interfaces give rise to metaphor-free computing in which reality itself becomes a direct user interface [http://wearcam.org/nime2007/mann.pdf].

Water is central to nature, and an important focus of this work. **An important goal of Hydraulikos is to allow us to touch and be touched by the most natural of all elements —- water** —- and to invent, develop, research, and teach technologies that facilitate a connection with our natural world.

HUMAN-ENVIRONMENT INTERACTION
Technologies like smart floors, smart elevators, smart streets, and other forms of "environmental intelligence" (i.e. of putting "intelligence" into our immediate environment) present unique challenges and opportunities. The new LED streetlights have video cameras in them that "watch" what people are doing and adjust the lighting according to use [Intellistreets, and Philips Lumimotion, for example]. Similar lights are being manufactured for indoor use as well [Texas Instruments, and

Lyrtech, for example]. Vision-based “smart lights” result in tremendous energy savings, as they adjust the light output “intelligently” based on the number of people present and what the people are doing.

Water is a unique and personal element in this context. When these same technologies are applied to water management, important new issues arise.

Some of my early work with water involved sensing and computation. For example, I invented a new kind of sensor-operated faucet that used artificial intelligence to do object-recognition, and adjusts the water according to sensed uses. It can distinguish the difference between, for example, tooth brushing, hand-washing, or filling a drinking bottle, and automatically adjusts the temperature, flow-rate, and degree of aeration (frothiness) to suit the task that it senses the user doing. See Fig. 1. Ten years ago I filed a patent (CA 2354113) for water management using image sensors, processors, and control systems.

Now a number of companies are using this vision-based water-sensing technology. Additionally I was involved in the design of mass causualty decontamination showers, using this technology, and my work was presented on Capitol Hill in Washington and is now being used in hospitals across the United States.

The vision-based water-controller developed in our lab resulted in another innovation: General Purpose Graphics Processing Units (GPGPU) which was invented in our lab at University of Toronto, and which resulted in a PhD thesis for my student James Fung, along with the development of OpenVIDIA in our lab (the predecessor of nVIDIA’s CUDA and of OpenCL). Fung is now well-placed at nVIDIA Corporation (world’s leader in graphics devices), and his GPGPU work is now taught in universities around the world, including our own University of Toronto.

Vision-based sensing in showers creates obvious privacy problems, and we had to invent additional technologies to solve these problems. That in itself requires that the research be cross-disciplinary, as it, by nature, must involve social, policy, ethical, and legal disciplines in addition to science, engineering, and mathematics.

Camera-based artifial intelligence systems are now used in water centres around the world to do automatic drowning detection, to count bathers (to automatically monitor bather-loads), to do automatic slip-and-fall detection in public washrooms, as well as to automate water flow and water management. For example, Texas Instruments has developed a camera-based vision system for use in washrooms, and Delta Faucet’s latest washroom automation devices (faucets, toilets, etc.) use a pixel array rather than just a single sensing element. These PSDs (‘Position Sensing Devices”) result in fewer false flushes and quicker-responding handwash faucets.

Additionally computer vision technology is used on public

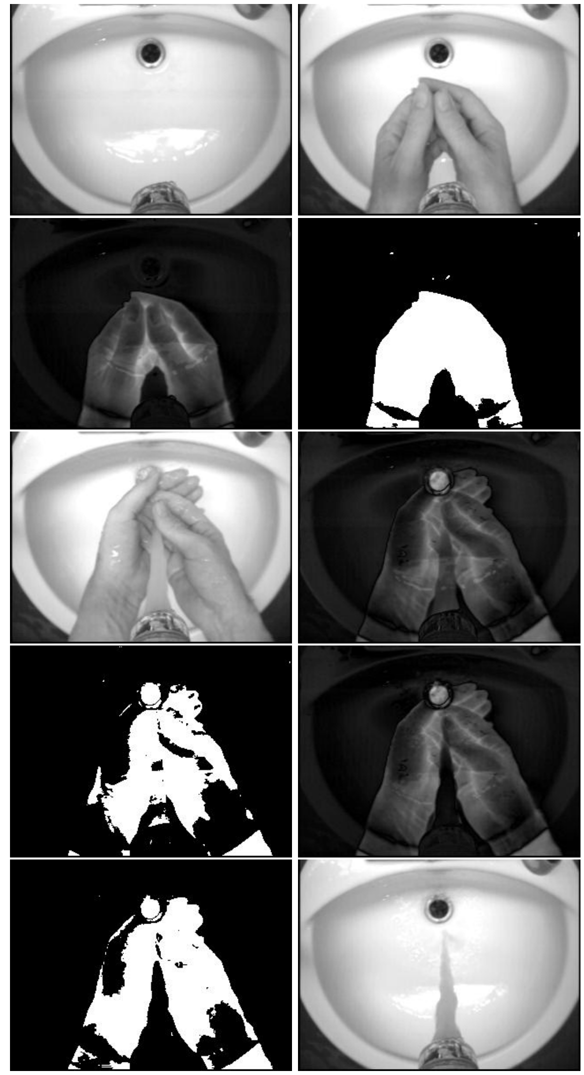


Figure 1. Experimental vision-based intelligent handwash faucet. An underwater camera in the faucet uses artificial intelligence and object recognition to automatically select temperature, flow-rate, and aeration based on identifying what the user is doing.

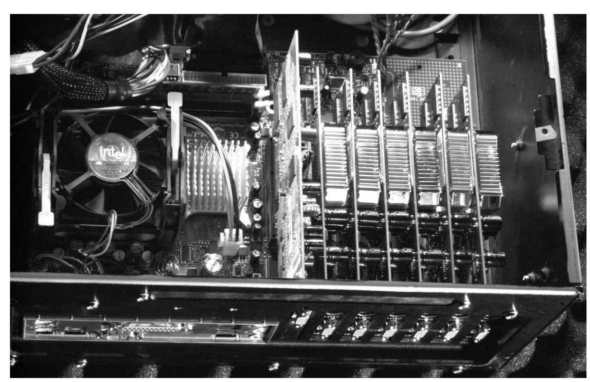


Figure 2. Early prototype of water-controller that spawned the field of GPGPU (General Purpose Graphics Processing Units.)

beaches to automatically count bathers (e.g. to automatically generate statistics of the number of sunbathers verus the number of people in the water), measure water height, rip currents, sand migration, and the like. ["How Many People in the Sandbox? An Application of Video Imagery to Quantifying Beach Use in Hawaii and Australia", by David Revell, ASBPA National Coastal Conference: Integrating Coastal Science and Policy, Tradewinds Island Resort, St. Pete Beach, FL, Tuesday, 2009 Oct. 13.]

Here in Ontario such technologies are at the planning stages. For example, the Toronto Waterfront is building an extensive CCTV surveillance system to monitor its lengths of beaches. Some have said that the Toronto waterfront will be the world's most technologically advanced waterfont community in the world:

> ... will include CCTV feeds from around the waterfront, allowing residents to check whether there is a seat available on Sugar Beach. Wiring the area is expected to cost $30-million in capital investment

["Ultra-high-speed broadband for a wired waterfront", by Siri Agrell, Globe and Mail, Jun 08, 2011.]

Perhaps this would make a good test-case for further research on the privacy-protecting computer vision technologies I developed originally for mass casualty decontamination showers.

Regardless, the work we undertake in the Water Centre will need to be both broad and deep, covering not just science and technology, but also arts, culture, law, ethics, and philosophy.

Water is so primal and universal that we must always think laterally. If we lock ourselves into the traditional academic "silos" of vertical-thinking and "problem solving", in matters pertaining to something as universal as water, we do so at our own peril.

WOIP: Water Over Internet Protocol

In this paper, I will introduce the notion of "water packets". Water packets are to Hydraulikos what data packets are to computing.

The WaterTouch technologies I describe and illustrate are what I believe to be the answer to connecting us with water. We all breathe the same air, and likewise, in a similar way, we all share the same water. A ramdomly selected drop of water from our Great Lakes has, on average, passed through 57 different people. Our bodies contain mostly (i.e. about 60%) water —- water that we all share. That we all literally are the body fluids of each other, underscores the "distributed" nature of water.

In my artistic and cultural discourse, I create art that is based on and inspired by cloud-based computing and the Internet.

Therefore Hydraulikos, by its very nature, will comprise various "nodes", analogous to the nodes of a computer network.

Figure 3. Early prototype of Hydraulikos water lab, powered by wind and solar.

A node might, for example, be a swim centre that is also a research facility.

What I have built is a "frolic lab" that can be replicated along the coast and along various rivers and watersheds.

A Hydraulikos node at a university might, for example, bring together the Faculty of Science, and the Faculty of Engineering, together with the Faculty of Physical Education and the Faculty of Music. A university pool, for example could be constructed in such a way that it can also function as a fluid dynamics research and teaching lab.

A greenhouse in a faculty of forestry might also function as a "bluehouse" with a miniature "teach beach" pond ecosystem and off-grid water features.

Science that can't be done on a lab bench

I do a wide range of scientific and experimental studies with and in water, where the scale of the experiment is too large to fit on a lab bench. For example, I developed some underwater resonators that are up to 20 feet (more than 6 metres) long, and a group of 12 of these comprise a music + water-therapy appratus.

I often end up needing to conduct this research in public pools (subject to permission of the lifeguards), public fountains (subject to absence of police or security guards), lakes and rivers (subject to weather and water conditions or other variables), or our condominium hot tub (subject to an absence of other users).

In 2001 my wife and I were expecting, so we were looking for a house to move into. We found a building suitable for my various experiments, which I equipped with wind, solar, and aquatics (Fig. 3). I built various large test-tanks and basins in which to conduct research in fluid dynamics and fluid flow channels, but as these setups evolved over the years, I began to realize the need for something beyond a water research lab —- something that could also, for example, facilitate community outreach.

Educational outreach: water activities where participants can touch and play with, and in water

Water has important therepeutic values [4].

The importance of water, and of clean lakes, rivers, etc., can-

Figure 4. Water, The Exhibition at the Royal Ontario Museum. The exhibit was both seminal and compelling —- with the quality and thought required of a world-class museum. However, the exhibit did not fully exploit the "hands-on" nature that water makes possible. In particular, due to the limitations of the museum building itself, there was no provision made for patrons to play in water, i.e. to "frolic" in this potentially interactive medium.

not be overemphasized, and indeed numerous research efforts, organizations, and facilities focus on water. For example, Columbia University has an Earth Institute and is home of the *Columbia Water Center*. Canada is home of some of the world's leading water centres, such as the City of Calgary's *Water Centre*, and Ontario's *Walkerton Clean Water Centre*.

Various educational programs use water in a variety of different ways. Some summer camps include a swim component, in which participants learn how to swim. Other educational efforts aim to teach the importance of clean lakes and rivers, or the like, as well as various scientific principles. Usually these two activities are separate. Thus immersion in the water (e.g. swimming) is a separate activity from scientific education, or the like.

A number of museum exhibits have been recently created in order to educate people about the importance of water, as well as scientific aspects related to water, hydraulics, and the like. These include the *Water Exhibit at California Museum in Sacramento*, the *Water Exhibit - American Museum of Natural History*, and *Water — The Exhibition* at the Royal Ontario Museum in Toronto, Ontario, Canada. See Fig 4.

These exhibits were seminal and well-executed. However, water is a new medium for most museums and centres, so in all of the above examples, the water was very well-contained, and mostly out-of-reach of museum patrons (no place to splash around and frolic!). But water, by its very nature, often draws people to want to splash, play, and frolic in it.

An important goal of this paper is to present water as an educational and *immersive* multimedium. When we study water without touching it, the water is less tangible and less real and immediate than when we study it by interacting directly with and in it. When we interact with and in water, we apply forces to the water, which create waves or other disturbances. Pressing against water in this way (i.e. applying *pressure* to it), whether with our fingers, hands, whole body, or the like, is what we mean by "hydraulikos".

We therefore use the world "hydraulikos" to denote the exploration of water by physically manipulating or touching it. Whereas currently existing Water Centres and Water Exhibits present, show, or study *water* in an abstract and indirect way, "hydraulikos" presents, shows, or studies *pressurized water* (water that is maniuplated, touched, or otherwise *pressurized* in some way by a participant).

THE VOICE OF WATER

My kindergarten teacher told me that there were three kinds of musical instruments: strings, percussion, and wind. But right behind her there was something called a piano, which is both strings and percussion. So I thought that the first two categories are more similar to each other than either is to the third, and asked myself what they have in common.... they both make sound from vibrating solid matter. Thus there are only two top-level taxons in this ontology: solid and gas.

I asked, "what if we made a musical instrument that made sound from vibrating liquid such as water?" and everyone thought I was crazy. So I invented a bunch of instruments that make sound from vibrating water alone, and called them "hydraulophones".

In 2004 here was an international call for artists and designers to create something for the Ontario Science Centre. I was among 240 applicants, and was one of the top 40 selected by an internationally acclaimed jury. We were each given funding to prepare a detailed proposal, and of these the hydraulophone ended up on the short-list of 10 to be presented in-person to the jury. The other 9 presenters, wearing business suits and ties, did a powerpoint-style presentation in the board room, but I'd asked merely for a garden house hookup outside.

When my turn came, I did my presentation outside, in my bathing suit, showing a contraption of PVC pipes hooked up to the water hose. The jury loved it, and it was selected for installation as the main centerpiece out in front of the Ontario Science Centre.

Now water has a "voice" for the first time in human history. We can now hear "the voice of water" a new sound never before heard in human history —- a sound that's at once sad and sweet and yet spiritually uplifting.

We have now created a series of hydraulophone exhibits and art installations throughout the world.

One of these exhibits is a musical instrument played by hitting water jets with the palms of the hands. The water jets flow from the mouths of an array of resonant hydraulic chambers made from simple butt-weld pipe fittings. See Fig 5.

Whereas water is not ordinarily thought of as compressible (i.e. water is often described as an incompressible fluid), the pipe fittings of Fig 5 provide sufficient containment to cause the water to be compressed under pressure of slapping the water jets with the palms of the hands of the player.

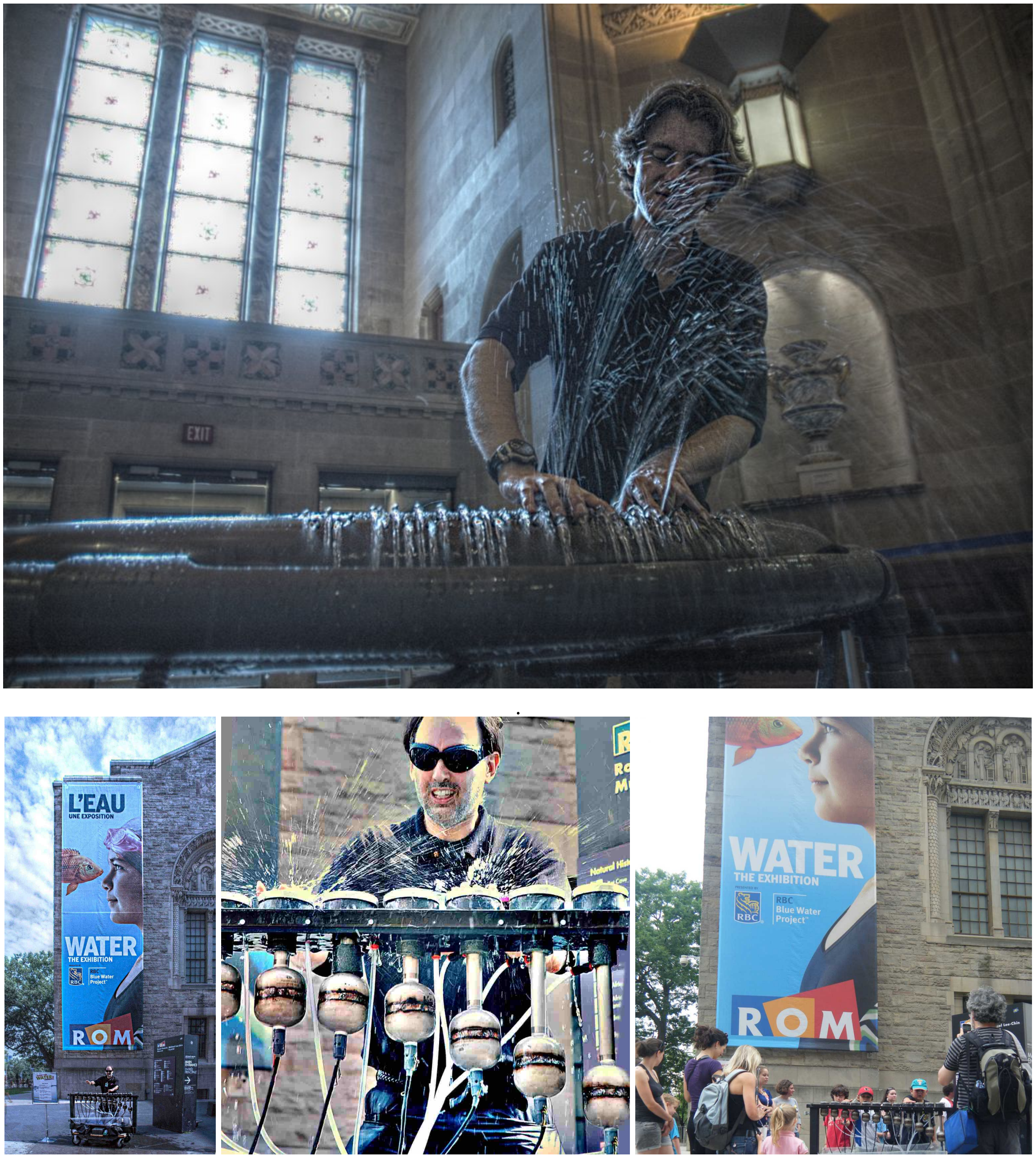


Figure 6. Author's *hydraulophone* (water instrument) formed the basis of a series of concerts and public demonstrations as part of the Royal Ontario Museum's official program for the Water Exhibit. This allowed patrons to understand water in a much different way. Rightmost picture: Patrons were also invited to play on and in the water, i.e. to *frolic* in the water, and thus experience water as an *immersive* educational multimedium.

Figure 5. A tangible user-interface invented by the author, presented at Science Rendezvous 2011. An array of hydraulic resontators made from butt-welded pipe fittings can house liquids at extremely high dynamic pressures. There are 12 water jets which are played by slapping the water surface with the palm of the hand. Sound comes from vibrations in the water. The result is a presentation of water as a medium for a musical instrument (e.g. *immersive* multimedia). The user interface is fun to play: Playing this instrument is like frolicking in a fountain!

.

Figure 7. Author's *hydraulophone* (water instrument) appeals to people of all ages and cultural backgrounds. It is perhaps the only aquatic play feature that has univesal appeal that washes away age differences.

More recently, the author and a collaborator (musician, composer, and scientist) were invited, by the ROM (Royal Ontario Museum), to be part of the official program, with one of the author's inventions. The invention, known as an *hydraulophone* [2], consisted of an array of tuned resonant water containers that produced sound by vibrations in water. See Fig 6.

HELPING THE DEAF, BLIND, AND ELDERLY

An important goal of the author's work is to use water as a universal medium to (1) reach people of all ages and (2) reach people of all abilities, including those with special needs.

A universal medium to connect people of all ages

Whereas most waterparks, waterplay features, and splash pads are designed for children, the author's water features are much like multimedia video games in which the water functions like a touch surface or game controller. Thus they obviously appeal to children, teenagers, *and* adults. Moreover, the water-based musical instruments evoke a kind of "sophisticated frolic" in which adults and even senior citizens enjoy playing jazz or classical music on a hydraulophone. See Fig 7. Non-musicians also enjoy experimenting with random sounds, regardless of age.

Whereas adults often shy away from standard aquatic play features, they are drawn, like children, to the hydraulophone, as well as the art installations like ARCHITouch.

Moreover, the gentle soothing touch of hydraulophone is being used to combine water therapy with music therapy, to help with arthritis, and to comfort cancer patients.

A universal medium to connect people of all abilities

Hydraulophones have long history of use as accessible technologies. Unlike air-based instruments, the water instruments produce sound in a medium that is more "feelable" than air. Whereas vibrations in air displace large volumes of air with rather weak force, the vibrations in water are much more forceful, and are therefore much more audible to the deaf, as mechanical vibrations.

In fact, the human body is made mostly of water (60%). Moreover, the body has an acoustic impedance of almost exactly that of water. Thus a water instrument makes an ideal "acoustic impedance match" to the human body, and is therefore the ideal medium with which to convey music to a deaf person.

The hydraulophone has a unique property that the sound is at once everywhere and nowhere in particular. The sound of a hydraulophone appears to come from all directions, and carries through the body of the instrument, through the ground, and through the player's hands and feet, as much as (or sometimes more than) it does through the air or the ears. Deaf musicians therefore greatly enjoy playing it. (See Fig ref8.)

Water is a natural and primordial medium that most people can immediately relate to. It has unique properties that make it understood by persons with special needs. For example, the author helped in the construction of the *Outdoor Classroom* where one of the author's musical instrument invention is being used by the CNIB(Canadian National Institute for the Blind). This variation of the instrument is played by gently touching water jets with the fingertips rather than striking the jets with the palms. Because of the multimedia and multi-sensory nature of water, the instrument is being used extensively for teaching music to deaf-blind children.

Additionally this version of the instrument is being used to help in the teaching of Braille, since the intricate touch and skills to play it translate directly to the intricate touch required of reading Braille. See Fig 9.

Figure 8. Deaf musician Evelyn Glennie playing hydraulophone. Hydraulophones are ideally suited to the deaf for 2 reasons: (1) they produce a high degree of musical content at low and even subsonic frequencies; and (2) the acoustic impedance of water is much closer to that of solid matter than it is to air. The sound produced by water is much more "feelable" than that produced by or in air. Thus hydraulophone is unique in its ability to reach the deaf.

Figure 9. Author's water-based musical instruments used at the CNIB (Canadian National Institute for the Blind), and in Eden Manor retirement home.

Figure 11. Concert performance for the pre-festival event that brought together a small group of approximately 150 distinguished guests, invited to inaugurate the efforts toward the water centre. The event included the unveilling of what might have been the world's largest musical instrument, an instrument made from the lake itself. The water platform supported an array of three-phase water pumps feeding into a lakewide resonant water vibration system.

ARCHITOUCH

In order to promote the idea of building the Ontario Water Centre, a water festival was recently organized, and attended by more than 2,000 people. The main event was a concert, situated on a platform in Lake Simcoe. See Fig 10.

The evening before the official start of the festival, there was a smaller private closed meeting for a smaller audience of distinguished guests (only approximately 150 people) specifically invited to inaugurate the efforts toward the Water Centre. This smaller private meeting also included an evening concert using the water stage and water instruments. See Fig 11.

In preparation for this pre-event, in addition to the water instruments, the author created an interactive water sculpture which each of the distinguished guests would be invited to experience.

An important design goal of this art installation was to facilitate aquatic play (i.e. frolicking in water) by people in formal business attire. For example, the Prime Minister, the Premiere, and the Mayor, among other distingushed guests, were invited to the event, and the author wished to have them be able to play in water in a very dramatic and splashful way, but without them getting soaking wet.

The author decided to use a laminar water arch, activated by participants when they blocked a much smaller water jet emerging from a decorative water fountain, as illustrated in the drawing of Fig 12. In a first embodiment of the piece, the "MagicFountain" consisted of a single-jet hydraulophone with a listening device and audio input to a computer (CPU) with a sound input. The computer then controlled a water pump in proportion to the blockage of the water jet on the "MagicFountain". Initially, a three-phase power controller was used, which could generate an arbitrary three-phase wave-

Figure 10. The water performances and water instruments were the main event at the SPLASH Water Festival 2011, attended by more than 2,000 people. The purpose of the festival was to draw attention to the need for clean lakes, as well as to bring together people to plan the creation of the Ontario Water Centre.

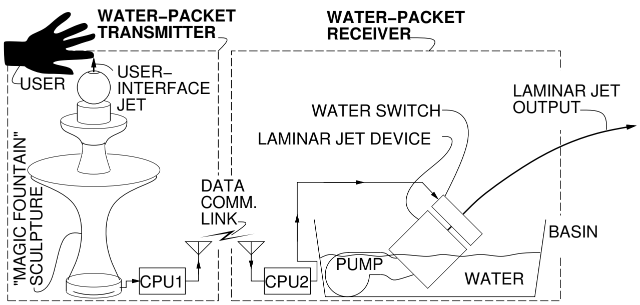


Figure 12. Author's water sculpture comprising a WATER-PACKET TRANSMITTER (a small garden fountain with a sensor that senses a USER touching the water), sending to a WATER-PACKET RECEIVER which includes a water-packet re-synthsizer, denoted WATER-PACKET RENDERER, to re-render packets of water. The effect is as if packets of water are data, which can be sent over a communications link. Blocking the "MagicFountain" causes the water jet at the right to spray in a way that intricately mimicks the blockage of the "MagicFountain". Water-packet response is extremely quick by way of a pump that constantly recirculates water until it is time for it to spray. Thus participants could create extremely short bursts, or long bursts, or any pattern like, for example, Morse Code, in which the "dots" (short water packets) and "dashes" (long water packets) all fly through the open air along the same parabolic trajectory.

form under program control from the CPU, over a wireless data communications link. However, it was found that the response was slow, due to the fact that water has to build up pressure.

A much faster-responding solution was therefore created where the water was circulated continuously in a basin, and simply redirected as the "LAMINAR JET OUTPUT" of Fig 12. This approach overcame the inertia of the water because only the direction of the water had to be changed (not its flow rate) and this could be done almost instantly.

Participants spoke of an ineffable sense of awe and wonder, as water packets could be sent from one place to another. There are two basins of recirculating water: one in the "MagicFountain" sculpture (transmit side), and another in the output "BASIN" (receive side of Fig 12). Through the communication of the "CPU"s (Central Procesing Units of Fig 12), a water-as-data (water packets being passed) metaphor arises between these two systems.

The author named this piece "ARCHITouch", and wrote the following text to be placed on a sign next to the piece:

```
Architouch

Try to stop me if you will
I'll keep on spraying, spraying still.
I am water, still as glass,
so block me, block me, still I pass.
```

The text was designed to be read by one of the facilitators who would guide each dignitary through the process of experienceing the piece. The following indicates the tempo, e.g. 4 beats per measure (i.e. 1 and 2 and 3 and 4) at which the text was to be read; capitalized text indicates emphasis:

```
1     and 2     and  3   and   4      and
----------------------------------------
TRY   to  STOP me    IF you   WILL,  i'll
KEEP  on  SPRAYing,  SPRAYing STILL.
I     am  WATer,     STILL as GLASS, so
BLOCK me, BLOCK me,  STILL i  PASS.
```

Text at beat 4 often introduces a double-entendre, e.g. Line 2, beat 4, the word "still" is a double entendre, meaning both continuance (as in "I'm still flowing") and stillness (as in the stillness of a glass rod). Line 4, beat 4, the world "PASS" means both "passing through a state of attempted blockage" but it also suggests a passage, e.g. a passageway under which the visitor is humbled to pass *below* the waterline. Thus visitors are literally underwater as they enter (but without getting wet).

Figure 13. ARCHITouch was tested in a wide range of public settings, such as in public fountains (leftmost) and (center) as well as wading pools and waterparks (rightmost). The picture at left shows a closeup of the author's "MagicFountain" sculpture which serves as the activator to activate the water arch (parabolic water arch laminar jet to the right) when the small water jet on the "MagicFountain" sculpture is blocked. This creates a natural user-interface, e.g. participants have the sense that blocking one water jet redirects the water out of the other water jet.

Figure 14. ARCHITouch setup at the festival venue, as activated by one of the conference organizers. When the small jet on the "Magic Fountain" sculpture is blocked, a much larger water jet sprays from the rain barrel, in a large arch above the entrance doorway under which each participant passed. (rightmost) The Mayor Robert Grossi activates the water arch by blocking the small pilot jet on the "MagicFountain".

Before bringing and setting up ARCHITouch for use by the dignitaries, the piece was field-tested in a wide variety of public settings. See Fig 13. One of the things that was learned from this preliminary testing was that some participants (e.g. small children and the elderly) had difficulty blocking the jet, so the apparatus was modified to make it much more sensitive. Additionally, it was found that some children would try to take the appratus apart, so it had to be re-designed to be more tamperproof. Moreover, because some people would wash their hands in the fountain, or pour sand into the fountain, a better filtration and water-treatment system was designed and built into the "MagicFountain".

Finally the ARCHITouch was unveilled for the dignataries at the water festival, as the first thing they experienced upon approaching the main entrance (See Fig 14). A second "MagicFountain" sculpture was also built inside the presentation venue. The second "MagicFountain" was used by the festival organizers to activate the main stage. The second ARCHITouch system was configured to activate a large three-phase contactor, so that power could be supplied to the building when the "MagicFountain" was touched by the conference organizers.

ARCHITouch allows a person to touch a tiny trickle of water and cause a massive spray to occur elsewhere. The two elements (the "MagicFountain" and Laminar jet output) can be located as far apart as desired. For example, an interface was created to allow "packets of water" to be sent over HTTP as WWW messages. Thus blocking a water jet in one country can spray a water jet in another country.

EARLY BATH

The author also built two identical copies of ARCHITouch, i.e. two *transmitters* ("MagicFountains") and two *receivers* (Laminar Jet Outputs).

A transmitter (Transmitter 1) and receiver (Receiver 1) are setup in one location (Location 1), and another transmitter (Transmitter 2) and receiver (Receiver 2) are set up in Location 2. The author configured Transmitter 1 to activate Receiver 2, and Transmitter 2 to activate Receiver 1, as shown in Fig 15.

In this configuration, the LAMINAR JET DEVICEs of Fig 15 are pointed at the user-interface water jets, as illustrated in Fig 16. The author named this piece "EarlyBath" or "Early Bather Advantage", since the first person to immerse their finger in the water jet has an advantage.

FIRST MOVER ADVANTAGE

Building upon the success of EarlyBath, the author created another interactive multimedia water game using two identical water jets, each equipped with a sensor (e.g. listening device) and a capacity for computer control of the strength of the same water spray jet used for sensing.

In this way, each jet becomes a water-packet transciever (i.e. both a transmitter and receiver of water data packets).

Initially both jets spray weakly, just a small trickle of water. When Jet 1 is blocked, Jet 2 sprays very strongly. When Jet 2 is blocked, Jet 1 sprays very strongly. This is done using the same technology as ARCHITouch/EarlyBath, but bidirectionally.

Each water jet was fitted with a hydraulophic listening de-

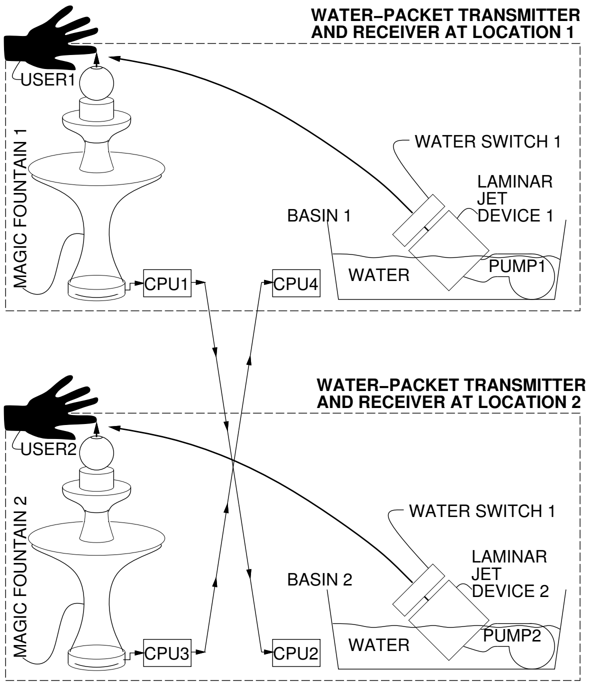


Figure 15. EarlyBath: An interactive art installation in which USER 1 can block the water jet on MagicFountain 1 to spray water at USER 2, and vice-versa. The first user to spray the other user gets an advantage, because it is more difficult to concentrate on the task of blocking the MagicFountain water jet when being sprayed with the much stronger LAMINAR JET DEVICE. Thus the EarlyBath art installation provides a "first bather advantage".

vice, to sense the degree of blockage.

Initially the water jets were co-located together in a parking lot at a street festival. The person who stomps on Jet 1 sprays the person who tries to stomp on Jet 2, and vice-versa. See Fig 17.

HEAD GAMES: LEARNING ON THE "TEACH BEACH"

An important goal of the author's work is education outreach, and fostering a DIY (Do-It-Yourself) culture of creativity. To begin this process, the author spent most of Summer 2011 doing weekly "teach-ins" at various beaches. The result was an approach to research through improvisation and tinkering.

All of the art pieces described so far are Fluid User Interfaces, i.e. touching water generates multimedia content, either mechanically (e.g. acoustically) or computationally.

Finally I present "HeadGames", a very simple, even primordial art installation using the most primitive of technologies, and doing nothing in response to touching the water, other than allowing the participant to feel the water itself at various quantities of head.

HeadGames teaches concepts of water pressure (head), and water-column, using a bucket hung from 3 pieces of driftwood. See Fig 18.

Figure 16. Two copies of ARCHITouch can be setup at different locations, so that, for example, people in different countries can have a waterfight with each other. In this case, the large-spray Laminar Jet Output parabolic arch is pointed at the user-interface jet, so that the participant can spray and be sprayed.

This allowed participants to experience varying degrees of head, e.g. zero (or 1 inch of head), versus a foot, then a metre, or two metres of head, etc., by either running their fingers down the water column and/or adjusting the height of the bucket when fed to a hose.

Many participants were amused and surprised by this installation. For example, most people were surpised at how easy it was to stop the water right at the hole in the bucket. This runs contrary to our everyday experience with city tap water which comes out of the tap at more than 100 feet of head (and is thus very difficult to stop).

With high-head water supplies that most people are accustomed to, the water feels stronger as you get closer to the opening. But the reverse is true with the bucket, and it was noteworthy that few people had experienced this very simple phenomenon before experiencing HeadGames.

The water opening in the bottom of the bucket was also connected to a hose so that the water in the bucket could be used to supply a hydraulophone (Fig 18, rightmost). The resulting gravity-fed water instrument became an interactive art installation in its own right. See Fig 19 and 20.

Other variations of HeadGames included a watefall made from a slot in a plastic case with a transparent lid, as shown in Fig 21.

HYDRAULICAMP: INNOVATION AND INVENTION AT THE NEXUS OF RESEARCH AND TEACHING

The author's own children have been involved in, been influenced by, or influenced the process of building the various hydraulic art installations. The children were hydraulists by the time they were less than one year old, and both took up

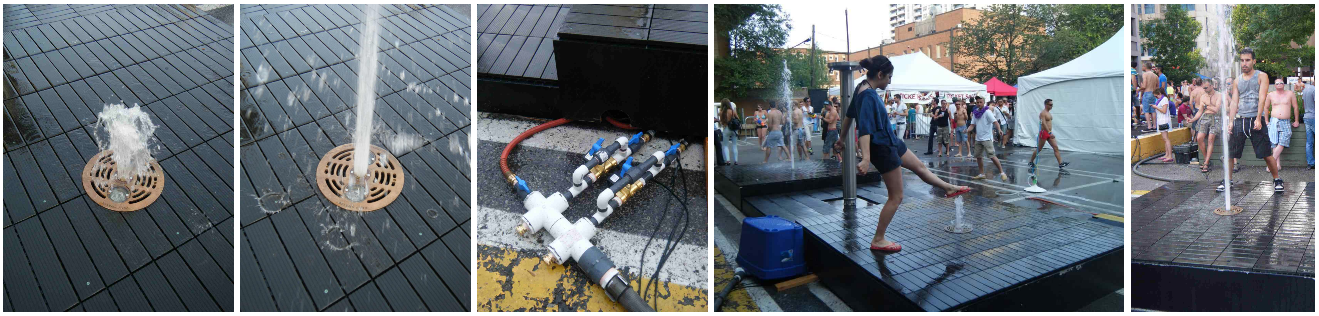


Figure 17. First Mover Advantage: Each jet is a water-packet transceiver, i.e. it can function as both a transmitter and receiver of water data packets. The jet can spray to varying degrees, and usually sprays at least a small amount of water (leftmost image) to sense when stepped on. A solenoid control system (middle image) varies the flow to the water jets. Stepping on Jet 1 makes Jet 2 spray extremely high and vice-versa. Thus the first person to step on a water jet gets an advantage ("First Mover Advantage") because the second mover (rightmost picture) must then stop a much more forceful water spray in order to retaliate, whether here in this waterfight across the parking lot, or in a similar waterfight across cyberspace.

Figure 18. HeadGames, an improvised DIY interactive art installation made from a discarded pickle barrel, scraps of rope, a pulley, and three pieces of driftwood. Participants were invited to feel the difference between zero or low head, near a hole in the bucket, or high head further down as the water fell. A musical water instrument (rightmost picture) was also fed from the bucket. This gravity-fed hydraulophone allowed participants to experience different amounts of head (water pressure), depending on the height of the bucket.

other instruments such as the violin by age 2 or 3. Additionally they became skilled in the art of do-it-yourself tinkering, and fixing their own hydraulophones; each has taken to liking a particular hydraulophone since age 2 or 3 (see Fig 22 and Fig 23.)

The children also became interested in various hydraulic sensors used in the project, and wanted to carry out some tests on water and hydraulic systems. (See Fig 24.)

TEACHING INTEGRAL CALCULUS USING WATERPLAY

Water flow creates a unique possibility for education. The author devised a way of teaching the concept of absement (the time-inegral of displacement) to children using a water valve and a bucket.

This method of teaching integral calculus was used by the Harbourfront Centre, beginning in 2008. See Fig 25.

TEACHBEACH: STEPS TOWARD A PERMANENT SITE FOR HYDRAULICAMP

Finally, the author built a small art installation called "Urbeach" on the rooftop of his studio. Urbeach is an art installation of fully functioning sustainability sculptures and includes the following:

- the world's first rooftop-mounted wind turbine;
- the world's first flexible solar roof membrane;
- Solouvre, a solar pergola sculpture;
- Solawings, a solar awning sculpture;
- a renewable energy lab;
- BlueRoof, an aquatic play facility and sculpture garden.

From sand to silicon

Urbeach is a metaphor for an urban beach, in which sand is replaced by silicon. Rather than sand, the substrate for Urbeach is the world's first flexible photovoltaic roof membrane. See Fig 26.

HYDRAULIKOS

Various people, including the author, envision the creation of a world epicentre of water research that might feature exhibits like the ones presented in this paper.

For example, a version of HeadGames might be built in the center of a circular staircase that would allow participants to safely reach out and feel a falling water column at various amounts of head, as they descend or ascend the staircase.

As a name for the Water Labs, the name "Hydraulikos" comes to mind. As mentioned previously, "hydraulikos" means

Figure 19. Gravity-fed hydraulophone (leftmost) is fitted with chalkboard rulers for teaching head pressure and potential energy. A participant paints a wooden plank with chalkboard paint and later annotates it with chalk. Second from right: A counterweight makes it easy for participants of all ages to adjust the head pressure on the hydraulophone, e.g. here the bucket is 6 feet in the air, giving two-and-a-half feet of head (i.e. subtracting the height of the instrument's fingerboard which is three-and-a-half feet off the ground). Rightmost, a 5-year old raises the counterweight to lower the bucket to a height of four-and-a-half feet. This is only one foot higher than the fingerboard. With only 1 foot of head, she can play a gentle lullaby on the hydraulophone.

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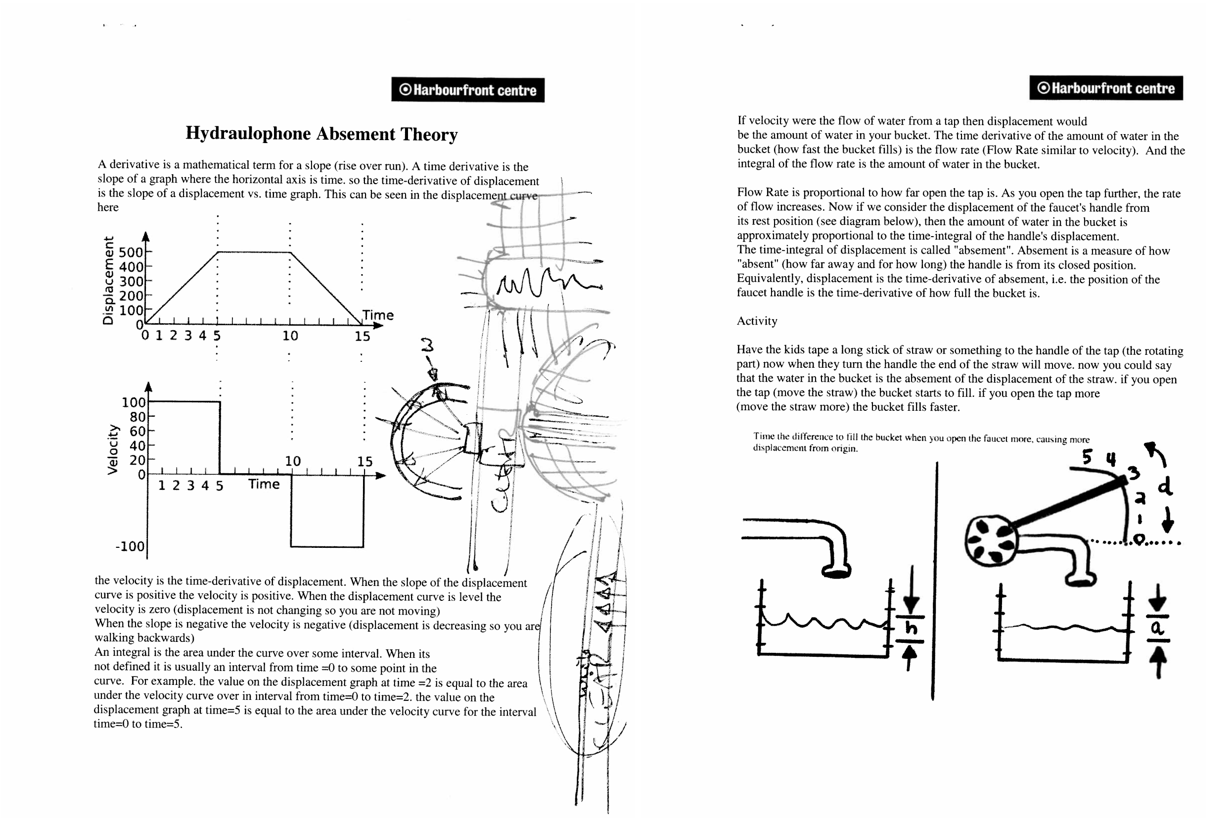
Figure 23. Stephanie, age 3, assembles her hydraulophone for a public demonstration at her child care centre. The instrument is entirely powered by solar energy from a 12-volt solar panel. By the age of 4, Stephanie subsequently aquired some skill at TIG-welding, including TIG welding aluminum and stainless steel.



⊙Harbourfront centre

Hydraulophone Absement Theory

A derivative is a mathematical term for a slope (rise over run). A time derivative is the slope of a graph where the horizontal axis is time. so the time-derivative of displacement is the slope of a displacement vs. time graph. This can be seen in the displacement curve here

the velocity is the time-derivative of displacement. When the slope of the displacement curve is positive the velocity is positive. When the displacement curve is level the velocity is zero (displacement is not changing so you are not moving)
When the slope is negative the velocity is negative (displacement is decreasing so you are walking backwards)
An integral is the area under the curve over some interval. When its not defined it is usually an interval from time =0 to some point in the curve. For example. the value on the displacement graph at time =2 is equal to the area under the velocity curve over in interval from time=0 to time=2. the value on the displacement graph at time=5 is equal to the area under the velocity curve for the interval time=0 to time=5.

⊙Harbourfront centre

If velocity were the flow of water from a tap then displacement would be the amount of water in your bucket. The time derivative of the amount of water in the bucket (how fast the bucket fills) is the flow rate (Flow Rate similar to velocity). And the integral of the flow rate is the amount of water in the bucket.

Flow Rate is proportional to how far open the tap is. As you open the tap further, the rate of flow increases. Now if we consider the displacement of the faucet's handle from its rest position (see diagram below), then the amount of water in the bucket is approximately proportional to the time-integral of the handle's displacement.
The time-integral of displacement is called "absement". Absement is a measure of how "absent" (how far away and for how long) the handle is from its closed position. Equivalently, displacement is the time-derivative of absement, i.e. the position of the faucet handle is the time-derivative of how full the bucket is.

Activity

Have the kids tape a long stick of straw or something to the handle of the tap (the rotating part) now when they turn the handle the end of the straw will move. now you could say that the water in the bucket is the absement of the displacement of the straw. if you open the tap (move the straw) the bucket starts to fill. if you open the tap more (move the straw more) the bucket fills faster.

Time the difference to fill the bucket when you open the faucet more, causing more displacement from origin.

Figure 25. The author helped create a teaching program that uses water to teach children, ages 7-13, integral calculus. The program was published March 13, 2008, by Harbourfront Centre, and deployed to hundreds of children in 2008.

Figure 26. From sand to silicon: Urbeach is like a beach but without the sand (top row). Instead, the emphasis is on renewable energy. The photovoltaic roof membrane is cooled by (and heats) the water from various aquatic play features. Additionally various sculptures form the basis of a sustainable energy lab (bottom row).

Figure 20. Gravity-fed hydraulophone with counterbalanced water supply bucket.

Figure 21. Another variation of HeadGames is an interactive waterfall. The ruler shows head in inches of water column. Additionally, a video camera inside the box allows a computer system to "see" down into the waterfall and measure the degree of touch, such as to make the waterfall into a touch screen surface. Note the solar panels in the background. All of the author's exhibits run on solar power or batteries charged by solar power. (Photograph retouched to make numbers on ruler legible.)

"water instrument" from which the world "hydraulics" is derived. Fig 27 is a children's rendition of what the Water Labs might look like.

CONCLUSION

A number of very simple art installations, exhibits, and the like were constructed to teach simple principles of water, and pressurized water (hydraulics), as well as to provide a sense of awe and wonder by facilitating unstructured play with and in water.

It is hoped that the success of this and other related work will help in the creation of "Hydraulikos, The Water Labs" that brings together art, science, technology (invention and innovation), research, education, and play.

ACKNOWLEDGEMENTS

The author would like to acknowledge the help of the participants, as well as Ladies of the Lake, and collaborators (H2Orchestra members including Ryan Janzen and Larissa Koniuk, and Evelyn Glennie), as well as Crystal Fountains.

Figure 22. Christina, age 3, unscrews each of the 21 screws from her hyraulophone to take it apart to clean the filters. She then finds the shortest route to run a hose from her hydraulophone up on a hill, to a nearby water supply.

Figure 24. Stephanie threads some water pipes onto flanges and connects up a a hydraulophone testing apparatus.

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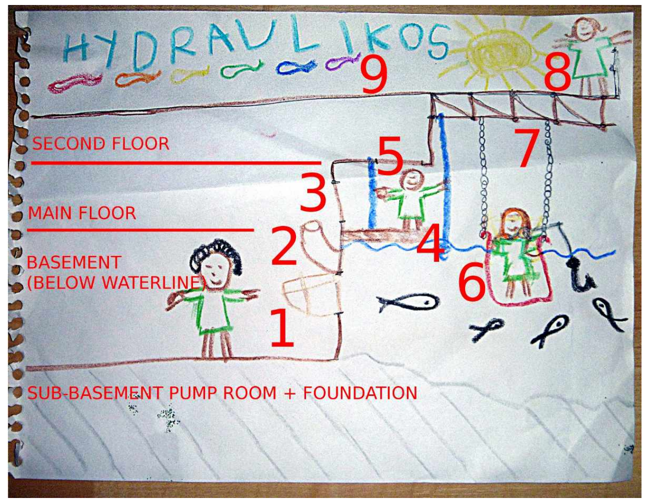

Figure 27. Children's rendition of the Water Labs called "Hydraulikos". Hydraulikos might be built right on a lake or other natural body of water. Some of the ideas that might be included could be (see reference numerals on drawing):
1, an underwater viewing window so people in the basement could look right out into the lake;
2, a swim pipe so people on the ground floor could swim down into the pipe and exit near the basement window;
3, a door on the main floor that leads to the lake;
4, a dock or deck at lake-level;
5, HeadGames fixtures suspended from the second floor of the building. The second floor of the building would extend out over the lake;
6, a floating hot tub, or perhaps a hot tub made to seem as if it were floating in the lake, by way of chains suspending it from a gantry. A child's vision is being able to experience fishing in the lake while soaking in the hot tub, and in the winter the hot tub would facilitate ice-fishing without feeling cold;
7, a gantry and rooftop deck that extends beyond the second floor, further out onto the lake;
8, possibly a waterslide or diving platform out where the lake is deeper;
9, six whale-shaped musical water instruments lined up in a row, in the colours of the rainbow, in a rooftop greenhouse that would also allow for year-round sunbathing.