Building virtual bridges everywhere: A report on the 2020 and 2021 Bridges online conferences

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The international Bridges Conference is the world's largest conference on mathematical connections in art, music, architecture, and culture. Since 1998, Bridges has traveled to North America, Europe, and Asia, and has attracted participants from over thirty countries.

In a typical year the Bridges conference is an eclectic mix of events ranging from traditional academic talks to a mathematical art exhibition and a fashion show. There are hands-on workshops, a mathematical poetry reading, a short film festival, theater and dance presentations, musical events, and a public Family Day of informal workshops for the local community. Participants include artists, mathematicians, computer scientists, and curious and creative people from many other fields. Academics and non-academics alike are welcome and comfortable in this rich environment of collaboration.

The Bridges conferences were born from the Art and Mathematics conferences held annually by mathematician and sculptor Nat Friedman at the State University in Albany, New York from 1992–1997. Carlo Sequin was one of many attendees who found the 1997 conference "particularly stimulating and contagious". Carlo was inspired to host the 1998 Art and Mathematics conference at the University of California, Berkeley. Many people were clearly excited about the possibilities for such meetings, as a total of six math and art conferences were held in 1998, including the first Bridges conference organized by Reza Sarhangi. Nat formed the International Society of the Arts, Mathematics, and Architecture (ISAMA) in 1998 and held the first ISAMA conference in San Sebastian, Spain in 1999.

With Reza's endless energy and warm personality, the Bridges conferences quickly became an annual gathering of people interested in exploring the rich interdisciplinary links between mathematics and the arts. The annual Bridges Proceedings, which contains a paper for every talk presented at the conference, became an important record of mathematics and arts research. In the Preface to the first Bridges Conference Proceedings Reza wrote, "A major reason for developing the Bridges Conference and this collection of papers is our desire to come together from a diverse set of apparently separated disciplines, to share and recognize abstract similarities, common patterns, and underlying characteristics".

While the Bridges Proceedings are an important collection of work, there are many restrictions that must be imposed on the papers given that the Proceedings are produced and published before the conference each year. A desire to allow more time to develop and refine articles and to publish art and mathematics research year-round led to the establishment of the Journal of Mathematics and the Arts (JMA) in 2007. JMA is not a Bridges publication, but many of the same people who love Bridges have been instrumental in founding, editing, and writing for JMA.

Reza organized the first five Bridges conferences at his home universities, Southwestern College in Winfield, Kansas (1998–2001) and Towson University in Maryland (2002). In 2003 Bridges became an international gathering when the meeting was held jointly with ISAMA at the University of Granada in Spain. After one more meeting in Winfield in 2004 the growing popularity of Bridges led to invitations to hold the conference at institutions across the globe. The 2005 meeting in Banff, Canada was followed by meetings in England, Spain, the Netherlands, Hungary, Portugal, Korea, Finland, Sweden, and Austria, with periodic meetings in North America scattered in between.

The 2020 conference was scheduled to be held at Aalto University in Helsinki and Espoo, Finland. The pandemic forced a cancellation of the in-person conference and a virtual version of the conference was quickly developed. Authors were encouraged, but not required to submit short videos or links to websites on their papers. The poetry reading was also assembled from contributed videos. Discussions were possible in the comments for each author's page, but this exchange was a poor substitute for in-person interactions. The 2020 conference website, with links to all these resources is permanently available at https://2020.bridgesmathart.org.

The Bridges conference Proceedings from every year are available for free at http://archive.bridgesmathart.org. The 2020 Proceedings contains papers relating mathematical topics such as topology, geometry, knot theory, combinatorics, and algebra to a huge variety of art forms, from fiber arts to poetry. Scrolling through the Proceeding one can find a wealth of exciting ideas to explore. From papers on experiencing geometric spaces such

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as *Non-Euclidean Billiards in VR*, by Jeff Weeks, and *Dancing the Quaternions*, by Karl Schaffer, to fiber arts like *Folding Fabric: Fashion from Origami*, by Uyen Nguyen, and *Knotty Knits are Tangles in Tori*, by Shashank G Markande and Elisabetta Matsumoto. Topology is explored in papers such as *Topological Classification of Vittorio Giorgini's Sculptures*, by Daniela Giorgi, Marco Del Francia, Massimo Ferri, and Paolo Cignoni, and *Maximizing the Symmetry of Knots,* by Peter Alexander Generao and Carlo H. Séquin. It is easy to spend hours roaming these enticing papers. You may find a paper like *Wallpaper Patterns from Nonplanar Chain Mail*, by Frank Farris or *Hilbert's Portrait via his Space-Filling Curve*, by Judy Holdener, is the perfect way to introduce your students to these topics.

As in other years, the pieces from the Exhibition of Mathematical Art are available at gallery.bridgesmathart.org/exhibitions. A beautiful color glossy catalog of the art exhibition is also published annually. But nothing can substitute for the experience of wandering the gallery and experiencing these eclectic displays in person. We also greatly missed the rich exchange of ideas possible when talking to each artist about their work.

A wide variety of artistic media were represented in the 2020 exhibition, including drawing, painting, beadwork, weaving, ceramics, woodwork, stained glass, metalwork, quilting, paper cutting and folding, and 2D and 3D digital prints. Artists drew inspiration from the mathematics of fractals, polyhedra, non-Euclidean and four-dimensional geometry, tiling, knot theory, number theory, and more. The incredible range of materials, techniques, and concepts is a visible display of the breadth and depth of mathematics and its applications. Professional artists exhibit their work alongside mathematicians and others with less formal artistic training. There is also some outstanding work by students. The result is a fascinating display that can be enjoyed by people with a huge variety of knowledge of art and mathematics.

A small example of the variety of media, techniques, and mathematics from the 2020 exhibition can be seen in the images in Figure 2. Ulrich Mikloweit is an artist who makes gorgeous polyhedra based paper sculptures cut and assembled entirely by hand. His 2020 contribution was a portrayal of the three stellations of the dodecahedron. Kerry Mitchell is a digital artist who uses his sophisticated knowledge of mathematics to produce beautiful designs. Judy Holdner is a mathematician who works in many media. Her 2020 contribution was a portrait of Hilbert using a 3D printed Hilbert curve. Of course, it wouldn't be 2020 without at least one abstract sculpture of a virus. Kacper Dobras and Briony Thomas created this colorful rendition of a polio virus.

Videos from the annual Bridges Short Film Festival are also posted at gallery.bridgesmathart.org/exhibitions. The creative diversity of the eight 2020 contributions is impressive. For example, *Spatial Variants of a Propeller*, by the Kocaeli Team, shows the filmmakers' inspiration for and development of a kinetic sculpture based on an iconic propeller displayed in Kocaeli, Turkey. George Hart's *Warped-Grid Jigsaw Puzzles* shows how to design complex puzzles using algorithms and transformations. The results are stunning works of art that can be assembled over and over. *The Arts of the Finite Topology Conjecture*, by Katrin Leschke, Chloe Aligianni, Lee Boyd Allatson, Jenny Hibberd, and Andrew Johnston, explores a collaboration between a mathematician, two musicians and a dancer and their interpretations of this conjecture. It is just a taste of what was clearly an exciting and rich experiment and is a great example for mathematicians and artists interested in such partnerships.

Figure 1. Bridges participants on the polyhedral climbing structure in the Mathematical Garden of the Tekniska Museet in Stockholm, Sweden (Equirectangular projection of spherical photograph by Henry Segerman)

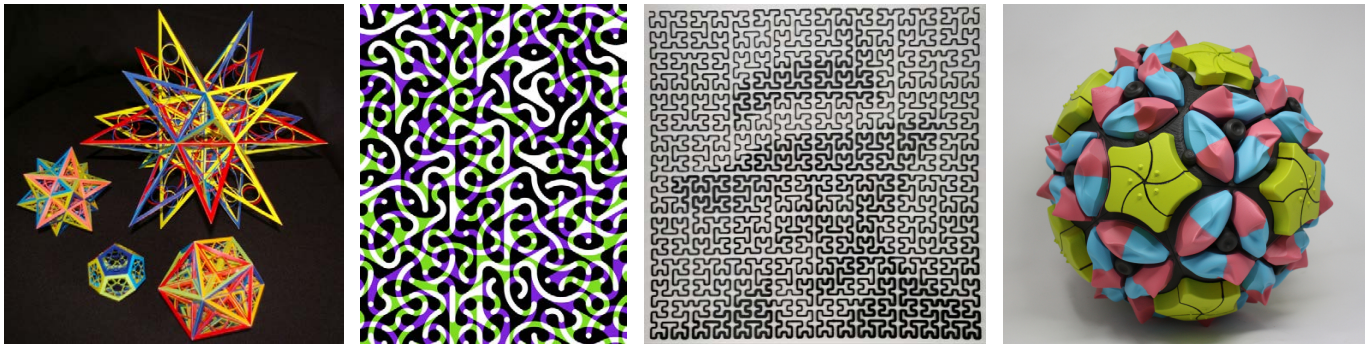

Figure 2. (a) *Four Dodecahedra*, by Ulrich Mikloweit, Freelance Artist, Germany. (b) *Truchet Bugaloo*, by Kerry Mitchell, Artist, USA. (c) *Hilbert*, Judy Holdener, Professor of Mathematics, Kenyon College, USA. (d) *PolioMechanics 1.0*, by Kacper Dobras, Research Assistant, and Briony Thomas, Lecturer in Design Science, School of Mechanical Engineering, University of Leeds, UK

The annual Bridges Mathematical Poetry reading is organized by Sarah Glaz. In 2020 this popular event was enacted via a collection of videos of poets reading their work and can be accessed through the 2020 virtual conference page https://2020.bridgesmathart.org under the Poetry Reading heading. The written versions of the poems can be found in the printed *Bridges 2020 Poetry Anthology*. Links to how to purchase this anthology and the three previous volumes are listed on the Poetry Reading page. The poems have multi-dimensional connections to mathematics and a wide range of styles, from traditional to lyrical and visual interpretations of this medium. 2020 titles include *I Forgot the Turnkey to the Void* by Carol Dorf, *The Mathematician's December*, by Sarah Glaz, *A Mother's Math is Never Done*, by Gizem Karaali, *How Taylor Series can Resonate on a First Date* by Lisa Lajeunesse, and *Singularity* by Mike Naylor. Mathematical Poetry is the perfect way to soothe and inspire a world in the midst of a pandemic.

Among the few live events held over Zoom for Bridges 2020 were four 90-minute workshops. Free registration was required to obtain the Zoom code and over 200 people from around the world signed up. Many first-time attendees were excited to be able to participate in a Bridges workshop without the expense of travel. Stephen Erfle and Katherine Erfle showed how to use Excel to explore a rich collection of symmetric patterns in *Exploring Symmetry using Aestheometry in Classrooms and Beyond*. This workshop would be a wonderful way to inspire students to explore the relationships between geometry, algebra, and simple number theory. In *A Two-Dimensional Introduction to Sashiko*, by Carol Hayes and Katherine Seaton, participants learned the history of this traditional Japanese needlework and the underlying mathematics as well has how to design and construct these pieces. Participants could experiment with needle and thread or pencil and paper. In António Araújo's workshop, *Dürer Machines Running Back and Forth*, he introduced his method for drawing anamorphic images. Attendees cheerfully shared photos of their drawings taken from the exact viewpoint that displays the perspective illusion. All the workshops generated wonderful discussions and were much needed opportunities for social interaction among Bridges friends new and old.

A few, less formal live events were also organized. These were listed under Social Events and Informal Gatherings and included a short meeting to exchange ideas about math and dance and a social hour. The last Social Event was an online version of Informal Music night, a campy mix of singing, dancing, and other performances by Bridges participants. In recent years the final act has been a conference song written and performed by Doug Norton. A video of Doug singing this year's rendition can be seen at http://2020.bridgesmathart.org/ under the heading "Wrap Up". The lyrics, sung to the tune "Rudolph the Red Nosed Reindeer," give a sense of the fun and creative environment of a Bridges conference:

We've had Bridges Linz, Waterloo, Banff, and Alhambra,
Towson, Jyväskylä, London, and Coimbra.
But what will Fate decree for bizarro year twenty-twenty?
Welcome to Bridges Nowhere! There's no need to rent a room.
No need to book that airfare: sign up for your space in Zoom.

They've wrapped up the Proceedings
(though we didn't quite proceed):
Lots of great math/art reading; entertainment guaranteed!
Knotty knits and trefoil knots, steganography,
Virtual reality, fractal cohomology,
Fashion-fold origami, labyrinths and spiroplots,
Lampshade Miura-ori, Morton's tritangentless knots.

Orbifolds and gyrations, tiles dendritic and Truchet,
Girih and pied-de-poule ones, hyperbolic plane crochet.

Coptic bananas, heptagons,
perhaps the plaintive numbers flow;

Hallå STEAM, platonicons, derivision, sgraffito.
Aalto, Espoo, Helsinki, Otaniemi.
Plans wrecked by COVID-19;
Unforeseen, quarantine, more hygiene, please, vaccine!
Very keen to reconvene, back on routine,
Back to the live math-art scene:

Beauty beyond perfection, augmented reality,
Math and art intersection, unveiling infinity!

The paradox of this pandemic is that we've learned how important face-to-face interaction is for learning and the exchange of ideas, yet we have been able to achieve surprisingly successful events online. The creative growth that this pandemic forced has led to many innovations.

For Bridges 2021 we are planning a greatly expanded virtual conference. There will be many more live events, including paper presentations, social events, a Mathematical Art Exhibition opening, workshops, and of course, Informal Music night. We will be using virtual spaces to host interactive events and to allow for more personal exchanges. For example, we will try to approximate the experience of the art exhibition with a virtual exhibition that participants can "walk through" and talk to the artists. Time will be scheduled for participants to discuss papers and ask questions of authors.

We anticipate a large international gathering. This is a wonderful chance for people to experience the Bridges conference from home and to increase awareness of the exciting current research in the growing field of mathematics and the arts. Information about how to register and attend is available at bridgesmathart.org.

It is with great hope that we plan to finally host Bridges Aalto in person in 2022. But for 2021, we hope to see you virtually!

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Eve Torrence is a professor of mathematics at Randolph-Macon College in Virginia, USA and a member of the Bridges Organization Board of Directors. She is the author of *Cut and Assemble Icosahedra: Twelve Models in White and Color* (Dover). Eve co-edited the 2016 and 2018 Bridges Conference Proceedings with her partner, Bruce Torrence. Other Torrence and Torrence collaborations include *The Student's Introduction to Mathematica and the Wolfram Language* (Cambridge), Mathematics Awareness Month 2014, and the raising of two wonderful children. Eve enjoys designing mathematical sculpture and incorporating the arts into teaching mathematics.

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Figure 3. An audience enjoys the outdoor debut of "Witches of Agnesi" at the 2018 Bridges conference (Photo by Bruce Torrence)