Recent Organ Design Innovations and the 21st-century "Hyperorgan"

– Randall Harlow (May 2011) –

The history of pipe organ construction and design is marked by technical and tonal change and design innovation. While organ builders developed new design innovations to suit shifting musical trends and the changing demands of players and composers, organ repertoire, written and improvised, can also be understood in the context of the organs available in specific regions at specific times. As a result of this reciprocal relationship, the organ has evolved over the course of a thousand years not so much as one instrument but as a diverse family of instruments, each offering a valuable window into the musical aesthetics of its time of construction (as well as dates of later modification or reconstruction). Five organs from the past sixty years offer particularly salient tokens of innovative design concepts. While these particular instruments illustrate the historical symbiotic relationship between composer, performer, and organ builder, their innovations in microtonal capabilities, spectral flexibility, and console control also greatly expand the potential value of the organ in 21st-century electro-acoustic composition.

This thesis is an in-depth examination of recent innovations in organ construction and design, looking at five specific builders and analyzing their work in the context of design dimensions relevant to contemporary electro-acoustic compositional techniques. The core of the paper will consist of an examination of the following instruments:

1. The thirty-one-tone organ by Adriaan Fokker in Amsterdam.
2. Peter Bares's organs in St. Peter's in Cologne, as well as its predecessor in Sinzig am Rhein, Germany.
3. The "Modulorgue" by Daniel Birouste and Michaël Fourcade in Aspiran, France.
4. The three prototype "Mit dem Wind spielen" organs by Peter Kraul and researchers in Bern, Switzerland.

5. The new symphonic organ by Gerald Woehl for the Musikhögskolan in Piteå, Sweden.

In each case I will discuss the underlying impetus behind the innovations, the musical/compositional aesthetics fundamental to the design, and the details behind some of the specific tonal, mechanical, and electronic innovations. The last part of the paper will examine how some of these recent innovations can be utilized to engage the organ with specific trends in music of our time. Focusing specifically on electro-acoustic music, including live-processing and DJ sampling, as well as music bridging multiple artistic modalities, I will illustrate how such innovations can be brought together to create a new "hyperorgan," an organ with extended capabilities that seamlessly blend the electronic and acoustic worlds along the lines of other hyper instruments developed by Tod Machover and researchers at the MIT Media Lab in the past twenty-five years. Finally, I will offer a practical proposal for a 21st-century update to the historic Kilbourn Hall Skinner organ, a proposal that would preserve the original integrity of the instrument while utilizing the latest technology to allow the instrument to be used in new ways relevant to the manifold domains of 21st-century electro-acoustic composition. This thesis offers a deep investigation into recent innovative organ design practices and illustrates their relevance for a new organ intrinsic to 21st century electro-acoustic composition.

In 1950, the Teyler's Museum in Haarlem saw the installation of a unique thirty-one-tone-per-octave pipe organ built by the Dutch organ-building firm Pels and designed by one of the museum curators. Curiously, the curator in question, the renowned professor of physics at the University of Leiden, Adriaan Daniël Fokker, was not on staff in the musical instrument or art department but was the museum's curator of the physical cabinet.[1] Fokker had studied under Albert Einstein and made significant contributions to the field of relativity, working with such luminaries at Max Planck and Hendrik Lorentz. However, with the closing of the universities during the Second World War, Fokker

[1] "Adriaan Daniël Fokker," Huygens-Fokker Foundation Centre for Microtonal Research, accessed March 26, 2011, http://www.huygens-fokker.org/whoswho/fokker.html.

took a side interest in music theory. With the publication of the twentieth volume of 17th-century physicist Christiaan Huygens's complete works in 1940, Fokker immersed himself in Huygens's less celebrated writings on musical tuning systems.

Remembered for his contributions to astronomy, physics, and mathematics, Christiaan Huygens (1629-1695), like many scholars of science in his day, shared an interest in music. Huygens was particularly interested in issues of just intonation and developed the mathematical foundations of thirty-one-tone equal temperament. In the 1691 letter "Lettre touchant le cycle harmonique" and the subsequent book *Novus cyclus harmonicus*, published posthumously in 1724, Huygens demonstrated how an equal-tempered thirty-one-tone tuning system closely approximates extended quarter-comma meantone.[2] However, Huygens was not the only theorist writing about thirty-one-tone tuning at the time. More than one hundred years earlier Nicola Vicentino experimented with a non-equal thirty-one-tone system and in 1555 invented a keyboard instrument capable of playing this extended quarter-comma meantone temperament, the 36-note Archicembalo.

Huygens's thirty-one-tone system posits a so-called "diesis" as the smallest fundamental interval. One-fifth of a major second and equal to the difference between the octave and three pure major thirds (a little more than double the syntonic comma), the diesis is the foundation of what Huygens defined as two categories of semitone: the *major* consisting of three dieses and a ratio of 15:16, and *minor* consisting of two dieses and a ratio of 24:25. When mapping onto pitch intervals, the major semitone would include C to Db, while the minor would include C to C#. After working out this tuning system to its natural conclusion, one is left with thirty-one notes to the octave, with close-to pure octaves, 5ths, 3rds, and 7ths. While these intervals are not precisely pure in thirty-one-tone equal temperament, Huygens demonstrated that their acoustic properties would make them indistinguishable from pure,

[2] Ibid.

with interference beats occurring at a rate of one per five or seven seconds.[3] Huygens thus developed a bottom-up approach to quarter-comma meantone to accomplish the same ends as Vicentino's top-down technique. However, while Vincentino's theories culminated in the Archicembalo, Huygens's work was largely forgotten and never put into practice.

With the republication of Huygens's writings in 1940, Adriaan Fokker was inspired to further develop the earlier physicist's theories and create a functional instrument built specifically for thirty-one-tone equal temperament. Fokker was also familiar with other theories of tuning being advanced in the first half of the 20th century. The Czech composer, folk music researcher, and theorist Alois Hába had advocated twenty-four-tone quarter-tone tuning, while Ferrucio Busoni advocated thirty-six-tone equal temperament in his 1907 *Sketch of a New Aesthetic of Music.*[4] In contrast to these subdivisions of the twelve-tone system, the thirty-one-tone system advances new interval cycles and more closely conforms to seven-limit just intonation[5]. To experiment with Huygens's tuning theories, in 1943 Fokker built a very small laboratory organ on which to explore the mathematics of so-called Euler-Fokker genera, while his music-theoretical work during the war was published in the 1945 book, *Rekenkundige bespiegeling der muziek.*[6]

Fokker recognized that a thirty-one-tone organ would be able to realize music of the late renaissance and early baroque according to some of the more outlying theoretical ideals of the time, such as those of Nicola Vicentino, Fabio Colonna, and Lemme Rossi. There are even examples of linear microtonal writing in some late baroque sources, including Charles de Lusse's *Air à la grecque*, while Fabio Colonna's *Esempio della circolatione* of 1618 specifically calls for a thirty-one-tone keyboard.

[3] Adriaan Fokker, "Equal Temperament and the Thirty-one-keyed rgan," *Scientific Monthly* 81 (1955): 161-6.

[4] Busoni, Ferrucio, *Sketch of a new esthetic of music*, trans. Th. Baker (New York: G. Schirmer, 1911): 19-20.

[5] The term "*n*-limit" was invented by American composer Harry Partch to describe a harmonic system wherein each interval is defined by a ratio of an odd number no larger than *n.*

[6] "Adriaan Daniël Fokker," Huygens-Fokker Foundation Centre for Microtonal Research, accessed March 26, 2011, http://www.huygens fokker.org/whoswho/fokker.html.

Most composers, however, did not seek universally pure tuning systems but composed expressly within the specific consonance-dissonance sound-world of quarter-comma meantone. While Fokker recognized the opportunity a thirty-one-tone organ would hold for certain austere performance practices of previous centuries, he more importantly believed that such an instrument would allow modern musicians to more fully explore music of other cultures as well as the sounds of the natural world. Fokker argues that the twelve-tone equal-tempered practice in Europe at the time was more or less the arbitrary result of history and points out that the historical development of music in earlier European culture and most cultures around the world has led to manifold tuning and scale systems.[7] Thus, an instrument tuned in thirty-one-tone equal temperament would open doors for musics of the future, free from the confines of twelve-tone practice and receptive to the expansion of European compositional practice receptive to multicultural syntheses.

In his plans for a thirty-one-tone organ, Fokker both eschewed the common practice of sub-semitone extensions to the traditional keyboard, as in the Archicembalo and other instruments from the period, and integrated some of the visual and physical characteristics of the traditional keyboard concept into a new mapping of key space. Indeed, the most salient feature of the instrument on first visual inspection is the keyboard. The keys on each of the two manuals lie in a two-dimensional array, in contrast to the linear white-black sequence of traditional keyboards. A grid of 28x6 keys is interlaced with a grid of 29x5 in a roofing tile pattern (Example 1). Spread across each of the nearly six-octave keyboards is the familiar pattern of white and black keys, however with some notable differences, including additional blue colored keys. Two black keys are situated between each white, the upper for flat and the lower for sharp. In addition, the traditional white/black pattern migrates up a step on each C and F in the array. The horizontal rows ascend by whole step, or five dieses. Counting across the right

[7] Fokker, "Equal Temperament," 161-6.

from C, for example, ascends C, D, E, F#, G#, A#, C-one-fifth-flat, etc. Thus, C moves a step up through each octave cycle. Interestingly, the ascending nature of the keys requires the Y-axis of the grid to extend high enough such that every pitch includes at least one redundancy on the keyboard, representing a kind of slanted cylindrical topology (i.e. ascending through the top of a vertical column of keys, one can continue to the bottom of another column offset to the left). This broad two-dimensional key array requires a button type action with small octave span more similar to the left hand keys on an accordion than to the lever action of a traditional keyboard. One intriguing consequence of this keyboard design is that every chord or pitch collection utilizes the exact same hand shape and finger position, regardless of where it lies on the keyboard. This, in contrast to the slight variations in hand position and finger extension necessary to play, for example, the twelve major triads on a traditional keyboard. The pedal board follows a similar pattern, spanning C to f^0 with lever keys in a cylindrical contour, rather than the flat button type array found in the manuals. Though the keyboards and pedal board have a very different span and feel as compared with traditional keyboard instruments, Fokker's thirty-one-tone design is surprisingly intuitive and more easily adaptable than its daunting appearance might indicate.

Nonetheless, given the radical nature of the thirty-one-tone design, Fokker anticipated the need for a traditional twelve-tone keyboard and had built an additional console whose twelve keys per octave could be assigned to a variety of configurations within the thirty-one-tone system. Nearly three hundred years earlier Huygens had designed a keyboard with the ability to shift across 31-strings per octave to accommodate meantone tuning relations starting on any pitch. While Huygens's shifting keyboard was never realized, Fokker's alternative twelve-tone console produces the same ends. Both consoles can be connected by umbilical cord to the electric action chests, and each operates five pipe ranks, two on each manual and one in the pedal. Fokker described the twelve-tone console as "looking back to the classical past," while the thirty-one-tone console was "the console looking to the future."[8]

Frequent performances on the organ followed its inauguration at the Teyler's Museum in September, 1951 until 1955, after which time a regular series of monthly concerts continued until the instrument was put into storage in 2000. The concerts featured a variety of works emphasizing the organ's capabilities for early repertoire as well as newly composed works exploring the possibilities inherent in thirty-one-tone pitch space.[9] Composers who have written works specifically for the Fokker organ include Henk Badings, Anton de Beer, Hans Eugen Frischknecht, Hans Kox, Alan Ridout, Ivan Wyschnegradsky, and Jos Zwaanenburg. While most of the works are for organ solo, several feature chamber ensembles with other microtonal instruments.[10] Most of these compositions contend with the instrument's ability to expand traditional harmony and often make prolific use of the diesis hyper-chromatic scale. While one might argue that the instrument generated works rather than fulfilled an existing demand, the fact that many of these composers were writing microtonal works for other instrumentats and that some of the works "premiered" on the Fokker organ were in fact arrangements of other microtonal compositions supports the assertion that the instrument helped fill a hole in the organ repertoire with respect to 20th-century microtonal composition. During the first fifty years of concerts, however, there does not seem to have been significant emphasis on incorporating the organ into ensembles of non-western instruments, as Fokker himself so enthusiastically advocated from the beginning.

[8] "Fokker organ," Huygens-Fokker Foundation Centre for Microtonal Research, accessed March 26, 2011, http://www.huygens-fokker.org/instruments/fokkerorgan.html.

[9] Ibid.

[10] "Sheet Music," Huygens-Fokker Foundation Centre for Microtonal Research, accessed March 26, 2011 http://www.huygens-fokker.org/music/sheetmusic.html.

This and other unique dimensions of the organ's capabilities are gaining new life, however, in concerts since its restoration in 2009. The Fokker organ was removed from the Teyler's Museum in 2000 and put into storage, where its future was uncertain. Fortunately, a permanent home was found in Amsterdam's new performance space, *Muziekgebouw aan 't IJ,* for both the organ and the Huygens-Fokker Foundation's new *Centrum voor microtonale muziek* (Center for Microtonal Music). The organ was thoroughly renovated and received its re-inauguration in May, 2009. During the renovation the pipe layout was changed, but the original chests were kept. Additionally, the consoles and electric action were rebuilt using up-to-date digital techniques and the instrument was installed in an intimate concert space high up in the Muziekgebouw. One of the key elements to the renovation was the "MIDI-fication" of the organ, electronic renovations which were handled by the Laukhuff organ firm from Germany. The analog umbilical console connections were replaced by simple MIDI In/Out cables and ports. Since 128 MIDI channels is not enough to accommodate six octaves of thirty-one notes, the velocity signal is split to allow MIDI to cover the full range of the instrument (in any case, velocity is not necessary for an organ, where a pipe is simply on or off with no dynamic flexibility). This allows other microtonal MIDI-capable keyboards to play the instrument. Similarly, any laptop computer can sync with the organ through a MIDI interface. Using the new versatile MIDI setup, multiple performers can play the organ by a variety of means, including direct computer-activated performance. In addition, ten buttons were installed on the console allowing the performer to activate patches preprogrammed in an intermediary computer. A renovation in the planning stages at the time of my research was the inclusion of an interactive LED lighting system, allowing the inclusion of a new variable modality during live performance while avoiding potential tuning disruption associated with the heat of incandescent lighting.

Since the May, 2009, inauguration, the Huygens-Fokker Foundation has initiated an annual six-concert season centered on the Fokker organ. Under Artistic Director Sander Germanus, the concerts have continued the tradition of the Teyler's Museum performances but have also incorporated parts of Fokker's multicultural vision and pursued avenues of performance unimagined by Fokker at the time of the organ's invention. For example, one concert in March, 2011, featured the organ alongside a Balinese Gamelan. According to Germanus, the thirty-one-tone equal temperament allows the division of the fifth into three in a manner similar to both the pelog and slendro scales of the Gamelan.[11] Thus, in contrast to the collision of cultures and temperaments evident in Richard Felciano's seminal 1977 organ-gamelan composition, *In Celebration of Golden Rain*, the organ is featured more at home among an ensemble foreign to conventional Western tuning systems. In 2010 jazz pianist Guus Janssen improvised on the organ, experimenting with microtonality in the jazz idiom, whereas in 2009 a program titled "Pimp My Organ" started an annual tradition of inviting composers to play the instrument directly from a computer, achieving sounds from the organ scarcely dreamed of before, such as ultra-fast glissandi and walls of sound similar to the filtering techniques of electronic synthesized composition.[12]

The Fokker organ, particularly in its new home in Amsterdam, has fulfilled a niche left wanting in the rest of the organ world. The fixed twelve-note tuning of traditional pipe organs has precluded their use in the microtonal music of mid-20th century composers. However, while the Fokker organ creates a role for the instrument in this body of repertoire, the concept has never caught on for a variety of reasons. Innovative as it is, and successful as it may be among the Amsterdam arts community, it is hard to predict what the instrument's future will be among the wider organ community. Since its creation sixty years ago, no other thirty-one-tone organs have been built. As a consequence, the impressive body of repertoire written for the Fokker organ remains relatively unknown and may forever be regarded as novelties of history unless other thirty-one-tone organs are built. Due to extreme tuning difficulties and unsuitability for the vast majority of organ repertoire, I do not see much promise for the

[11] "Concerts," Huygens-Fokker Foundation Centre for Microtonal Research, accessed March 26, 2011, http://www.huygens-fokker.org/activities/concerts/fokkerorganconcerts.html.

[12] Ibid.

future of thirty-one-tone pipe organs. However, I believe there may be great potential in the world of electronic instruments. Perhaps the greatest triumph of Fokker's invention lies in the unique and remarkably effective keyboard design. Taken by itself as a means for artistic control over a sound medium, the design of the console is an ideal system with which to transmit thirty-one-tone or other complex microtonal soundscapes.

As a portable instrument activating electronic or sampled sounds, the Fokker organ console design may prove to be a versatile addition to the diverse designs of microtonal instruments that have emerged over the past half century and continue to engage artists committed to transcending the cultural straightjackets of Western tuning traditions. In fact, the Huygens-Fokker Foundation has recognized the potential of Fokker's extraordinarily efficient design and is working on just such a digitized mobile version of the organ. Adriaan Fokker's thirty-one-tone equal-tempered organ represents an extreme and unusual innovation in contemporary organ-building. Through the use of the thirty-one-tone equal-tempered tuning system coupled with an effective keyboard design and 21st-century electronic innovations, it fulfills Fokker's vision of an instrument that can both play microtonal music from the past and pave the way for music of the future.

Two organs built under the direction of German composer and organist Peter Bares exhibit innovations in areas of sonic design and expansion of tonal resources. Born and educated in Essen, Bares demonstrated an early interest as an organist in both free atonality and Gregorian chant. During his years as organist at St. Peter's Church in Sinzig am Rhein, he sought contemporary musical means with which to express his musical theology through the organ and choir. Loathing what he saw as the encroaching influence of popular taste in sacred music, he tirelessly pursued his own musical visions, often in direct conflict with the clergy. These conflicts eventually resulted in his dismissal from Sinzig in

1985 and retirement from active church music.[13] He remains active as a composer, lecturer and, until 2008, a concert performer. Due to his high regard among organ and composition circles in and around Cologne for his creative visions for organs suitable for new music, he was invited to direct the radical renovation of the organ in Cologne's *Kunst-Station Sankt Peter* in 2004. Bares's conception of the organ as a great synthesis of art and engineering capable of endless tonal and artistic expansion can be clearly seen in his own words, "Eine Orgel ist eigentlich nie groß genug. Dabei ist nicht die Lautstärke, sondern das Potential an Farbe und Geist entscheidend. Die Orgel ist ein hochgeistiges Instrument, weil sie alle Künste und Techniken in sich vereinigt" (An organ is never actually big enough. This is not the volume, but the potential of color and spirit. The organ is a highly intellectual instrument, because in it all arts and techniques are united).[14]

His innovative organ concept can be best summarized as the pursuit of maximum color, though (1) vast arrays of distinctive reed stops, (2) mutations and mixtures comprised of unorthodox partials, and (3) extensive percussion batteries.

The renovations Bares made in collaboration with Werner Walcker-Mayer to the Walcker organ in Sinzig from 1972-79 exhibit many of these characteristics. In addition to the usual Nazard and Tierce mutations and quint-based mixtures, the organ offers the selection of some very unusual partials. Rare, but not entirely unheard of, the inspiration for these registers can be traced to earlier instruments by the Marcussen firm in Stockholm and Göteborg, the aesthetics of composer Bengt Hambraeus and the

[13] Michael Gassman, "Der Bewahrer des Neuen: Peter Bares im Portrait," in *Werkzeuge der Stille: Die neuen Orgeln in Sankt Peter zu Köln,* eds. Michael Gassmann, Karl Wilhelm Boll, and Kurt Danch (Cologne: Wienand Verlag, 2004): 55-6.

[14] Peter Bares, "Maß und Zahl: Über Orgeln und Musik," in *Werkzeuge der Stille,* 60.

"New Organ Style" of the 1960s, and the theories of German organ scholar and clergyman Ernst Karl Rössler in the 1940s:[15]

1. "Fünfzehn 8/15" on manual I (the manuals are labeled top to bottom III-II-I, with II acting as the Hauptwerk): major seventh above 1' pitch.
2. "Mollterz 16/19" on manual II: minor third above 1' pitch.
3. "Obert. 1 1/7, 2 fach" on manual I: the seventh and eleventh harmonics above 8' pitch.
4. "Theor. 6 2/5, 3 fach" in the Pedal: 6 2/5, 4 4/7 and 2 2/3, amounting to a major third, minor seventh, and perfect twelfth above 8' pitch.

All mutation and mixture ranks are tuned pure. By combining some of these stops with 8' ranks one can achieve some very unusual timbres. These stops also work well in the lower registers in combination with 2' or 1' ranks, producing growling sonorities similar to electronic additive synthesis. The combination of the minor third, fifteenth, and seventh and eleventh mixture along with a 2' rank produces a rather convincing carillon sound in the lower registers. With these unique mutations and mixtures Bares allows the organist to play the instrument almost in the manner of an analog synthesizer. The Sinzig organ also contains several unusual percussion stops. Manual I features a xylophone stop at 4' pitch with single hit and continuous roll options. Manual III contains a "Psalter" stop, presumably referring to the harp- or zither-like instrument dating back to ancient Greece. It produces a continuous metallic rattle that is nominally pitched, though not in any corresponding relation to the keyboard. By itself, the Psalter is a puzzling inclusion, providing neither rhythmic clarity nor pitched timbre variety. However, when played in combination with a broad plenum of principals, mutations, and mixtures, its cloud of high shimmering sound mixes with the unusual partials of the mutations and mixtures to create the effect of an electronic sound mass produced through noise filtering.

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[15] Martin Herchenröder, "From Darmstadt to Stockholm: Tracing the Swedish Contribution to the Development of a New Organ Style," in *The Organ as a Mirror of its Time*, ed. Kerala J. Snyder (Oxford and New York: Oxford University Press, 2002): 310-11.

Among other interesting features of the Sinzig organ is a programmable mixture on Manual II. This "Mixturen Setzer" is activated by pressing one of twelve buttons in an array on the left side of the console. With the buttons arranged in the manner of a chromatic scale starting on C, the organist can select a mixture comprised of any interval class from one through eleven (Example 2). However, since the intervals are equal-tempered and are comprised of the same ranks of pipes as those being played, this programmable mixture might better be described as a chromatic coupler. In addition, a sustain function is possible using a swell pedal. The notes on Manual II and any manuals coupled to it, including the programmable mixture, are held as long as the pedal is depressed, much like the piano's sustaining pedal. Similarly, a nearby toe stud labeled "Tastenfessel" sustains any notes played on Manual II (but not those coupled to it) until pressed again.

One other curious feature is a system called "Percuss. Glocken" activated by buttons on the side of the console. Two rows of reversible buttons control a repetitive chime (Example 9). The first row, numbered one through nine, plays the chime once during a specified time interval (this interval can be controlled by the knob below the buttons) and at any of nine subdivisions. For example, pressing the first and fourth buttons would activate a loop of the first chime followed by a second four-ninths of a second later. Another row of six buttons activates a similar one-second loop, but this time the first chime is higher in pitch and the others subdivide the beat at a ratio corresponding to their number. For instance, pressing the first and third buttons would set up a triplet loop in an Oom-pah-pah, Oom-pah-pah pattern, or the first and fifth buttons together would set up a quintuplet pattern. It is hard to speculate what purpose Bares envisioned for such a system. Perhaps the six-level system could be used to accompany a metrically stable piece or improvisation, such as a processional on a special feast day. The complex ratios of the nine-level system, on the other hand, could create the effect of unsynchronized bell cycles as part of a free improvisation.

Like the organ in Sinzig, the new organs in St. Peter's Church, Cologne feature many reed, mutation, and percussion stops in addition to unique console devices; however these later instruments develop the Sinzig ideas into a more unified tonal concept. An active Jesuit church whose structure dates back to the 12th century, St. Peter's in Cologne became home to the new "Kunst-Station" in 1987. Established as a center for contemporary art, the Station offers residences for artists and composers and features regular concerts, art installations, and readings. The large modernist case in the back balcony, incorporating the pipework of the previous neo-baroque organ, plus the newer eight-meter-tall choir organ situated on the floor in the front left side easily dominate the interior visual space. While the choir organ boasts its own three-manual console, the four-manual detached console in the balcony can play both, allowing the two instruments to work together as one. Both were built under Bares's guidance by the Cologne firm Willi Peter Orgelbau. Full specifications of the organs as well as explanations from many of the musicians and builders involved with their creation and current performance is available in two volumes titled *Werkzeuge der Stille.*[16]

Colorful mutations and mixtures abound, including numerous sevenths, ninths, and elevenths. The four Cymbel mixtures on the floating Koppelwerk feature highly unusual partials, including 2/13, 2/15, 2/17, 2/19, 4/21, and 8/27. In addition to a full battery of reeds in each division, manual II features a free-reed Physharmonika at 8', 16', 32', and 64' pitches, while the Koppelwerk contains a Saxophon at 4', 8', 16', and 32' pitches. There is a programmable mixture, or chromatic coupler, using the Sinzig push-button layout, available at any and all intervals one octave above as well as one octave below the given pitch. We find many of the same percussion, including a Psalterium.   Additionally, the console features a sustain capability much the same as that in Sinzig.

[16] Gassmann, Boll, and Danch, eds., *Werkzeuge der Stille*; Michael Gassmann, ed., *Werkzeuge der Stille II: Die neuen Orgeln in Sankt Peter zu Köln* (Cologne: Fries Printmedien, 2007).

In addition to expanding many of the Sinzig features, the Cologne instruments contain several new ideas. For example, a "Bass Organum" stop in the pedal couples the pedal to itself at a fourth below and major third above the given pitch. In addition a knob at the left of the console can vary the blower power from zero to full. The effect of altering an organ's blowers while the instrument is playing, resulting in a gradual destabilizing and sinking of the sound, has been explored since the 1962 Radio Bremen compositions. However, in contrast to simply switching the power on and off, the knob on the Cologne organ permits quick and efficient destabilization under complete control of the performer. The Cologne organ also permits MIDI in/out, allowing the organ to be played by or in collaboration with a computer, much in the same manner as the Fokker organ after renovation. One final novel addition is a rotation function for the Koppelwerk Cymbal mixtures. Labeled "Quadrupla" I through V, each setting mixes the four cymbals in diverse ways, creating varied complex mixture compositions. The first four settings represent miscellaneous fixed arrangements, while the fifth cycles through the first four at speeds variable by knobs situated below the buttons, creating a constantly shifting and somewhat aleatoric overtone structure within held notes.

Throughout history organ builders have incorporated new sounds and specifications to suit the tastes of the time. In the Sinzig and Cologne organs, Peter Bares has created instruments intended for experimentation in certain musical parameters. In the spirit of the new spectral approach to organ composition begun in the 1960s by such composers as Bengt Hambraeus, Mauricio Kagel, and György Ligeti, as well as organist Karl-Erik Welin, these organs offer composers a palette of sounds with which to mold complex and dynamic soundscapes – soundscapes inspired by the electronic additive and FM synthesis compositions of the 1950s and 60s. The enthusiasm for the Cologne organ among current composers is evident through the numerous works composed for the instrument since its inauguration six years ago. Current organist Dominik Susteck has released two recordings of the organ and is engaged year-round performing and hosting guest performers for a variety of concerts, often in collaboration with artists in other mediums. Listening to Susteck play the Cologne instruments, one is struck by a rich plasticity of sound. The strange high partials blend seamlessly with the shimmering percussion, building to a great roar, or sinking through warbling tones detuned through a shifting wind supply, a sound reminiscent of early Penderecki, Stockhausen's electronic soundscapes, or contemporary spectralist composers such as Tristan Murail or Kaija Saariaho.

One of the most significant efforts in recent decades to pursue new approaches to organ-building through primarily mechanical innovation can be found in the organs of Bern and Biel, Switzerland, associated with builder Peter Kraul. Taking a flexible approach to wind control as a point of departure, these instruments, and the multi-disciplinary project that launched them can be traced back to the ideas of Swiss organist Daniel Glaus in 1997-98. Composer and professor at the Bern University of the Arts and the Zurich School of Music, Drama, and Dance, Glaus has long sought new ways to transcend the inherent limitations of the organ, limitations which have been associated with the instrument throughout history and which have led to what he sees as its increasing irrelevance among composers of the 20th century.[17] In Glaus's view, these limitations can largely be attributed to the instrument's inflexible wind, leading to lack of subtle timbre and dynamic flexibility.

While a strong stable wind supply has undeniable benefits in many situations, organs and builders throughout history have sought new means for a "cantabile" capability on the organ, a capability that, in Glaus's opinion, Bach found so admirable in the clavichord.[18] Johann Andreas Stein's late 18th century organ-like Melodica was said to be able to change dynamics through variation in key

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[17] Daniel Glaus, "From Wish to Reality: Experience and Performance," in *Fresh Wind: The Research Organs of Bern University of the Arts,* eds. Michael Eidenbenz, Daniel Glaus, and Peter Kraut (Saarbrücken, Germany: PFAU-Verlag, 2006), 79.

[18] Ibid, 80.

pressure.[19] The European "discovery" of the free reed at the end of the 18th century led to the invention of the expressive harmonium by Alexandre Debain in the 1840s and later perfection by Victor Mustel.[20] Additionally, free reeds were incorporated by organ builders, including Walcker Orgelbau, as expressive stops in the early 19th century. Later in the century, Italian organ builder Giambattista Guiseppe De Lorenzi adapted some of the concepts of the concert harmonium to the pipe organ, building an organ with similar expressive capabilities in 1878. The system, called the "Fonocromico," is built around a keyboard suspended by springs wherein a swell box is opened through the application of significant weight to the keyboard after the key has reached the bottom of its motion. Additionally, each key is capable of dynamic expression by means of doubled ranks. Each pitch in a rank consists of two pipes, the valve for the second of which opens after the key is depressed a certain distance beyond the activation of the first.[21]

During a 1999 symposium in Biel, Switzerland, the discussions Glaus had been having among his colleagues concerning flexible wind and the expressive organ led to the initiation of a four-year research project, linking the School of Music in Bern-Biel, the College of Engineering and Architecture in Biel, and the Zürich School of Music.[22] In addition to Glaus, the research group was to include Peter Kraul, an organ builder based in Germany with an interest in flexible actions; Johannes Röhrig, a Swiss organ builder specializing in experimental pipe construction; and Daniel Debrunner, a professor of electric control technology at the College of Engineering and Information Technology in Biel/Burgdorf.

The ongoing project's stated areas of study include exploration of issues of flexible wind systems in conjunction with sensitive mechanical keyboard actions; proportional valve technology and innovative

[19] Robin Blanton, "The Stein Claviorganum, and the Construction of Art in the Late 18th Century," (Paper presented at the Research Symposium of the Göteborg International Organ Academy, Göteborg, Sweden, August 2009).

[20] Though new to Europe, free reeds had been used for hundreds of years in the mouth organs of East Asia.

[21] Michael Eidenbenz, "Swell Shutters, Wind Swells, and Other Swell Engines: the Historical Pursuit of Organ Expressivity," in *Fresh Wind*, 93.

[22] Michael Eidenbenz, "From Test Rig to Instrument: the Chronology of a Research Project" in *Fresh Wind*, 66.

pipe design; and outreach to composers, performers, and audiences. Within two years, two prototypes were completed. Following the completion of Prototype II in 2001, composers began to create works taking full advantage of the instrument's unique expressive and acoustic properties. In 2003 the research group received expansive funding from the Swiss National Science Foundation's DORE initiative leading to the four-year "INNOV-ORGANUM" research project. Building upon the results of innovations in the first two prototypes, a more substantial Prototype III was completed in 2004 and installed in the Great Concert Hall of the Bern University of the Arts before being moved to Biel parish church. Performances on Prototypes II and III have included new works by composers Juhee Chung, Hans Eugen Frischknecht, Jürg Lindenberg, and Hansheinz Schneeberger.[23] At the time of my meeting with Peter Kraul in August 2009, all the prototypes had been moved to Bern Münster, with plans for a more practical full-scale organ to be installed in Biel parish church incorporating many, but not all, of the elements of the first prototypes.

Perhaps the greatest challenge set forth by Daniel Glaus in the early stages of the research group was to pursue a wind system and action that would allow expressive dynamic and pitch flexibility at the organ keyboard similar to effects obtained on the clavichord. Glaus's vision was intended not only as an attempt to better realize the aims of past builders, but also to build an organ more amenable to contemporary compositional tastes. Through discussions with composers, Glaus came to the conclusion that the primary reason for the organ's persistent rejection lies in its lack of dynamic, pitch and timbre flexibility. As early as 1906 Arnold Schönberg declared his disdain for contemporary organs, saying,

[23] Glaus, "From Wish to Reality," 81.

> "Man hat Recht, die Orgel die Königin der Instrumente zu nennen, von ihrer Majestät zu sprechen, und sie zu beherrschen ist wirklich ein aristokratisches Vergnügen."[24]
> "Man is right to call the organ the queen of instruments and speak of its majesty, for she is the master of aristocratic pleasure."

By "aristocratic pleasure" Schönberg clearly intends to relegate the organ to a past aesthetic, unsuitable for his musical vision. However, in a letter to Werner David in 1949, Schönberg discussed what he believed to be the ideal organ for his musical aesthetic. It should have permit dynamic variation of each and every tone independently over a range of seven or eight octaves and contain only a few registers, each of which should be capable of the widest dynamic expression[25]. Throughout the 20th and into the 21st centuries, composers have been interested in instruments capable of micro control over the broadest range of musical parameters, be it in search of spectral flexibility or total serialization.

As discussed earlier, instrument builders including Stein and De Lorenzi found various solutions to allow dynamic control by the finger on the keyboard. Fortunately, Peter Kraul had a similar interest in direct expressive control and had developed a radical new design involving a double wind chest with differing actions and wind pressures. The first concrete realization of the flexible wind ideas of Kraul and the reference group came to life in Prototype I. A laboratory device with three keys and five stops, Prototype I contains an impressive variety of strictly mechanical design innovations, the most salient of which is the double pallet box. Two pallets can be found at the head of each of the three wind channels: a traditional tail-pallet in the chest below, and a specially designed cone-pallet in a chest above the wind channel (example 3). The cone-pallet features a disc-and-cone design that when lifted gradually increases the cross section of the aperture, essentially eliminating pluck and allowing sensitive control of

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[24] Arnold Schönberg, "Die Zukunft der Orgel" (unpublished essay, Arnold Schönberg Center, Vienna, Austria, 1906/07), quoted in Matthias Giesen, "Arnold Schönberg und die Orgel," *Österreichisches Orgelforum* 7 (June 2005): 14.
[25] Eidenbenz, "Swell Shudders, Wind Swells," 91.

the onset of pipe speech. The wind pressure in each pallet box can be set independently, while the valves for each key can be activated together or independently (either through decoupling the cone valve or shutting off wind in the traditional pallet box while coupled to the cone action). Additionally, a system of squares on an adjustable beam can be used to manipulate the tracker transmission ratios, and a roller beneath the keys allows for variable key depth adjustment. Acting together, these devices for wind and action variability allow for a wide variety of touch and pipe-speech control. For example, using the variable ratios one can simulate the touch of organs ranging from plucky tracker action to the mushy resistance of a Barker lever, or test the speech of a pipe from the fastest to the slowest pallet speeds.[26]

In Prototype II, the concepts set forth as laboratory experiments in Prototype I are put to expanded use in a much larger instrument capable of wide-ranging musical expression. Prototype II again features the dual tail-cone wind chest design and features three ranks playable by one keyboard of twenty-five notes (c-c^2). The wind pressure in the traditional pallet box is set at 42mm Water Column (WC) while the cone-pallet box is adjustable from 0 to 150mm WC; non-return flaps in the key channels prevent the higher pressure air from returning through the lower pressure pallet. A weight mounted on a track along the length of a wedge-bellows is movable by a hand crank below the keyboard controls to adjust wind pressure to the cone-pallet box (example 4). This variable-pressure mechanism necessitates the only use of electric technology in the instrument. Two electrical contacts along the chain signal the blower to increase power from 50 Hz to 65 and 75 Hz to supply the necessary wind. However, through the creative design of human-powered wedge bellows one could theoretically eliminate this lone modern contrivance.

Four mechanical drawstops control the adjustable components of the mechanical action:

I. *Trakturübersetzung*: varies the tracker action ratios in the traditional pallet box.

II. *Tastentiefgang*: sets the maximum key depth.

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[26] Peter Kraul, "Three Prototypes: Pushing the Technical Boundaries in Organ-Building" in *Fresh Wind*, 71.

III. *Kegelübersetzung*: adjusts the key-to-pallet ratio from 1:2 to 5:1 using a variable fulcrum under the backfalls of the conical transmission.

IV. *Kegel an – ab*: couples the cone action to the tail-pallet action, allowing cone action activation at variable key depth though intermediate settings.

In addition, a flat beam containing springs can be mounted under the keyboard to correspond with the cone-pallet coupler setting. By setting the wind pressure of the cone-pallet chest somewhat higher than that of the tail chest, and carefully adjusting the cone action transmission ratio along with a delayed coupler action, one can obtain the flexible *bebung* effect so sought after by Daniel Glaus and the research group. This effect results from the rapid variation of wind pressure as the finger engages and releases the cone-pallet, creating vibrato in both pitch and dynamics. The optional springs under the keyboard can be set so as to provide resistance to the key at the point where the cone action engages the tail action. Recognizing the potential pitfall of the expressive cone action (organists tend to find a complete lack of pluck or point of sound onset disconcerting), the builders included this artificial haptic mechanism to allow more natural control of expressive effects, simulating the increased resistance in the string of a clavichord when depressed beyond initial impact.

While the dual wind system and variable mechanical properties of the key action allow unprecedented control over dynamics and tuning using only the motion of the finger, the widely variable wind pressure also reveals the diverse acoustic properties of the pipes themselves. Three metal ranks of differing scales were chosen to examine the effects of varying wind pressure dynamics: a wide 8’ Flute, a normal width 4’ Principal, and a very narrow 8’ Quintade which overblows at the quint at the tail-pallet box’s 42 mm WC.[27] The Flute and Principal jump an octave at high pressures, while the

[27] Ibid., 73.

Quintade can be heard at the 8' fundamental using low pressure on the cone-pallet box and can then overblow to the tierce at 90 mm WC.

By applying and improving upon the basic innovations of Prototype I, the researchers were successful in achieving one of the primary aims of the project in Prototype II through expressive flexible wind and key action offering control over pitch and dynamics comparable to that of the clavichord. With the possibility to expand this research further through the INNOV-ORGANUM project, the research group set about incorporating their advances into a full-size organ. Prototype III features three manuals (C-c^4) and pedal (C-g^1) with five ranks of pipes: Prinzipal 8', Gedackt 8', Flöte 4', Quinte 2 2/3' and Terz 1 3/5'. The upper Manual I operates the cone-pallets while the tail-pallets are operated by the lowest Manual III. The middle Manual II functions as the coupler, with the expressive clavichord-like capabilities of Prototype II. The wind pressure in each of the pallet boxes can be varied independently from 0 to 150 mm WC by means of two swell pedals. Drawknobs on the left of the console are marked with a calibration of 1 through 10 and activate the stop sliders, two sets of which allow independent slider control for each of the two pallet boxes. An additional calibrated drawknob on the left activates the Windharfe, a partial rank of pipes (c-c^3) tuned to length but lacking reeds or mouths, producing a sound partway between pitch and white noise. Four drawknobs on the right control the transmission ratios and key depth of cone and tail-pallet actions, while additional pedals in the feet double the action of three of these knobs. Transmission ratios in Prototype III extend beyond those of its predecessor: 1:2 to 6:1 for the cone-pallets and 1:2 to 8:1 for the tail-pallets (Example 5). However, the variable cone-pallet coupler was not retained in Prototype III, which instead has a fixed 5-mm delay for the coupling Manual II. Couplers in the pedal can pull down one or both pallets, where one can obtain sensitive clavichord-like action through half-coupling the cone-pallet box. Finally, four levers above the pedals control a "Windstösse," allowing the player to add or take away a blast of wind from either of the pallet boxes. By using these levers one can obtain especially fine control over dynamics and pitch of the pipes

(Example 6). For example, they can be used to provide a blast of accent, or add a controlled tremulant to a keyboard, not unlike the Bebung effect of the middle manual.

As with Prototype II, the variable wind pressure facilitates a wide range of sounds and pitches in each rank of pipes. The 4' flute and mutations, all overblown at the tuning wind pressure of 45 mm WC, jump down into their 8' fundamentals and reveal delicate colors at low wind pressures. The pitch of the Gedackt does not respond to wind pressure change, but rather the rank takes on an impressive variety of speech characteristics at high and low pressures or through manipulation of the action-transmission ratio and key dip. At high pressures the pipes in the other ranks overblow into higher partials, including the seventh and ninth in the tierce. Additionally, one can carefully adjust the wind pressure to the unstable point just below or above a rank's break and utilize the Windstösse to pop the rank to an upper or lower partial. One can also obtain multiphonic effects in some of the stops, particularly at points where the pipe is overblown into an upper partial but still rests at an unstable point.

Through these three research prototype organs, this extraordinary multidisciplinary project has realized to a great extent the vision put forth by Daniel Glaus for the "emancipation for the pipes."[28] Perhaps for the first time in history the organist can take complete control over the wind; shaping dynamics and pitch from gestures of subtle beauty to blasts of sound and multiphonic spectral soundscapes comparable to the extended performance techniques developed by other instrumentalists throughout the 20th century. Composers have already expressed interest in the expressive possibilities for the instrument, and the research group continues to promote new works and host performances on the two later prototypes. What is extraordinary is that the technical achievements these instruments represent are the result of nothing more than brilliant mechanical engineering. With the exception of the electrical pickups for the wind regulation, there is nothing about these instruments that could not have been built three hundred years ago.

[28] Glaus, "From Wish to Reality," 83.

Even considering the project's tremendous success at expanding the capabilities of the pipe organ, the prototypes do have their limitations and drawbacks. Glaus points out that through the experience gleaned from Prototype III, the team has learned that the specifications for achieving a successful clavichord-like organ are likely very different from those for an "organ of the 21st century." In attempting to fulfill both purposes, Prototype III falls somewhat short. According to Glaus the clavichord-like organ should have a heavier action in the tail-pallets, but with a clear pluck point at the onset of the cone valves followed by less resistance over a deeper key depth. Additionally, the wind pressure need not offer such wide fluctuation, but could be effective with 20 to 30mm WC flexible range. He also feels that overblown stops are not suitable for the music of Bach. Rather, Glaus believes that a battery of open flutes, principals, and strings would offer a more effective firmament of sound upon which to play early music with subtle expressive tonal variation.[29]

Glaus proposes that the next prototype consist of one expressive division as part of a larger more traditional organ. I had the same thought after getting to know Prototype III. It is a research tool, of course, so it may be excused for possibly having too many features in one package. I believe some of the more successful aspects of the design could be incorporated into more traditional future instruments. An example could be an expressive division with the double-pallet system on two non-fluctuating wind supplies. Eliminating the possibility for endless wind pressure variation would simplify the playing process and narrow the focus of the division, using two fixed but slightly differing wind pressures in a coupled tail-cone-pallet configuration to allow subtle expressive clavichord type effects. Another option might be a spectral division with a single valve and highly variable wind pressure suitable to manipulate a battery of specially voiced pipes for overblowing and multiphonic effects. This could be an effective option for an organ designed with more contemporary uses in mind, such as in a municipal concert hall or university performance space. One innovation that could be applied to organs of any

[29] Ibid., 84.

style, even added to some existing instruments, is the Windstösse lever. By connecting this simple and clever mechanism from the bellows to levers in the feet, the player has the option of adding subtle vibrato, Bebung, or breaths of wind to his playing. By attaching the mechanism to schwimmer bellows one could conceivably create the possibility for directly manipulated wind flexibility separately in each division.

Perhaps the chief problem with Prototypes II and especially III is that they can prove very difficult to play. Or, to be more precise, they are difficult to play and achieve a high level of precision. One is never sure exactly how much the pitch is going to bend or exactly where the stops will overblow. Additionally, when playing the expressive manual, it can be difficult to stress one voice among a wider texture, a difficulty not unlike playing a theater organ double-touch keyboard. While the imprecision and aleatoric nature of Prototype III makes it very difficult to achieve a precise effect, it can also be liberating to the improviser. Spending a couple hours freely improvising on the instrument in Bern Münster, I found myself lost in the pleasure of the sheer freedom it affords. It is a wonderful instrument for improvisation, as well as an effective instrument for liturgical purposes (with the possible exception of supporting congregational song – thus its "Prototype" designation as a research instrument). The flipside of this, however, is that it is not only a difficult instrument with which to play with precision, but it is a very difficult instrument for which to notate. Some of the composers who have written for Prototype III have struggled with just this issue. Daniel Glaus, for example, found the prospect so daunting that he had not, as of 2006, composed for the instrument himself (though he quite often improvises on it). Hans Eugen Frishknecht has come up with a set of guidelines and notations expressly designed for Prototype III. In my view, however, his guidelines are often too specific and as a result can be difficult to implement. He specifies the exact position of the drawknobs and degree of fluctuating wind pressure in many cases. It may prove more effective to notate the desired sound result rather than micromanage the precise means to the end. By considering notation in this way, one can help transform organs like Prototype II and III into dynamic instruments demanding a new technique which, like that of any other instrument, must be learned and perfected over time.

One final application for instruments like Prototypes II and III worth exploring would as pedagogical tools. After the session with which I had to play them and examine the internal mechanisms, I walked away with renewed knowledge about the fundamentals of pipe organ design and mechanics. Prototype III, for example, would offer students an outstanding hands-on laboratory with which to learn about organ construction and design and pipe voicing and acoustics. It is designed to be packed in a crate and shipped off in less than two days. Three or four organ departments at Universities in America or around the world could combine funding and jointly purchase such an instrument, allowing it to rotate yearly or semi-yearly among the institutions.

The three prototypes developed by the Swiss research group and the INNOV-ORGANUM project represent tremendous innovations in modern organ-building. Through exceptional vision and brilliant engineering, they have created organs with unparalleled expressive capabilities offering new ways to play existing repertoire as well as spectral flexibility pointing the way to repertoire of the future.

Where the organs of Peter Kraul and the Swiss research group take mechanical innovation as the point of departure, the "Modulorgue" concept put forth by French organ builders Daniel Birouste and Mickaël Fourcade seeks to realize new expressive and musical capabilities through the application of innovative technology. Birouste, a master organ builder with more than thirty years of experience, along with Fourcade and a small team of engineers and carpenters, has developed a new concept for future organ design, including an ambitious business model aimed at maximizing the potential outreach in a wide variety of social contexts. The first such installation of the Modulorgue concept was completed in Aspiran, France, in 2007.

The basic concept behind the Modulorgue is a unit chest coupled with innovative valve technology and sophisticated electronic control mechanisms. In starting with the unit chest concept, wherein an electronic valve is placed under every pipe, Birouste and Fourcade aim to maximize the potential of every pipe, a concept they refer to as Individual Pipe Control, or IPC.[30] Recognizing the inherent drawbacks of the unit chest design that have plagued organ builders since its advent with Robert Hope-Jones and the Wurlitzer company nearly one hundred years ago, Birouste and Fourcade devised a series of technological solutions which would allow a small number of ranks to act in consort to achieve the diversity of sound of a much larger instrument. The most obvious downsides of a highly unified organ are the holes produced in the sound caused by the failure of a pipe in use to be reactivated in a separate albeit synchronous context. For example, when playing a unified rank of Principal pipes at 8' and 4' pitch, that is, the 4' pitch operate the same pipes an octave higher, any key that is depressed while the corresponding key an octave lower is also depressed will activate only the 4' pitch above the key, the unison already sounding as the 4' to the key an octave below. Through digitized intervention in the key-pipe signal matrix, the IPC system of the Modulorgue automatically rearticulates any pipe whose redundant use is demanded by the performer.

Another key component of the IPC concept is the integration of digital valve technology. A new valve developed by Modulorgue team member Francis Bras frees the electric valve mechanism from its traditional binary confines. Since the advent of electro-pneumatic action in latter half of the 19th century, and purely electric action in the 20th, organists playing non-tracker mechanisms were resigned to a loss of control over the onset of the pipe. After depressing the key a specified distance an electrical signal would be sent to an electromagnetic valve under the pipe which would in turn release the air, the reverse procedure occurring on the release. In other words a pipe is either on or off, in contrast to the analog physical manipulation of the pallet valve through mechanical means. Bras' digital valves, on the other hand, are built with a series of steps between the fully open and closed positions. The opening and closing of the valve could thus be modeled to follow the key displacement function, not unlike

[30] "Concept," Modulorgue, accessed March 22, 2011, http://www.modulorgue.com/concept.html.

traditional tracker action. This concept of a digital value had been gaining traction in several organ-building circles around the time of Bras' development. As part of the Swiss consortium research project discussed above, electrical engineering professor Daniel Debrunner was researching a similar proportional electronic valve technology, though it never reached full implementation. At the same time, the NovelOrg company in Montreal was in the early stages of developing a proportional mechanism to electronically transfer or recreate mechanical key action. With the concept of Individual Pipe Control through original electronic programming and innovative digital valve technology, Birouste and Fourcade and the Modulorgue team found new means to liberate the pipes from the role of "slave interpreter" ("interprète asservi"[31]) within each rank, a liberation with similar ends, albeit through diametrically opposed means, to Daniel Glaus's goal of "emancipation for the pipes" discussed above.

The first major realization of the Modulorgue concept offers insight into the new possibilities afforded through IPC. Installed in the small village of Aspiran in Hérault, this instrument is called the "Mobilorgue," a terminology predating the Modulorgue of today. The term, however, accurately reflects the most salient feature of the instrument. Consisting of a moveable console (two 61 note manuals and 32 note pedal) connected to two divisions, each housed in an enclosed case mounted on shocks and rollers, the entire instrument is designed to be thoroughly mobile (Example 7). It has been moved to various parts of the sancuary for services, concerts, and demonstrations, and as has even been rolled out into the square for outdoor performances. Each division contains two ranks of pipes, each rank comprising approximately eight-four pipes. Through unification, each division is stretched to accommodate nine stops, with four stops available in the pedal.[32] Additionally, two 16' ranks in the pedal, two pedal reeds, 8' and 16', Bourdon 16' and Sesquialtera II in the Grand-Orgue, and a Voix céleste in the Récit exist as electronic samples, a compromise specific to this organ due to its size and

[31] Ibid.

[32] "Aspiran," Modulorgue, accessed March 22, 2011, http://www.modulorgue.com/aspiran.html.

role as a prototype. While the Récit contains a large battery of mutations, through a Septième and Neuvième, the unification of the rank of course requires that they be equally-tempered.

In addition to the usual combination and sequencer pistons, the Mobilorgue console takes full advantage of the IPC design and features several innovative controls effecting duration, pitch, and pipe speech. Two toe studs offer sustain features on each of the manuals. The stud can be activated in one of two ways: holding it down sustains whatever is being played for the duration of its depression, or quickly touching the stud activates the sustain, to be released by a subsequent touch. In such a way this system combines the separate capabilities of the sustain pedal and stud on the Bares organs into a single button. The sustain principal has a history dating back at least to early Wurlitzer designs and can be found on the organs of several large French cathedrals that some recent composers, most notably Jean-Louis Florentz, have utilized in their organ compositions. Allowing the organist to sustain a collection of pitches frees up one hand and consequently opens the door to vastly more complex textures.

Perhaps the most innovative realization of IPC potential can be found in a series of controls on each side of the keyboards (Example 8). Here, dials can be used to manipulate the pitch and speech of each rank independently. Two *Transposition* dials can be set up to thirty-six steps above the played pitch. This is analogous to the chromatic mixtures of the Bares organs, though with a larger range and a maximum of two addition pitches. As with the mutations, however, these mixture combinations are equally-tempered and thus do not offer a sound comparable to traditional purely tuned mixtures. The *Attaque* dial determines the maximum opening of the valve on a scale of 0 to 100. The *Velocité* dial sets the threshold at which the *Transposition* and *Attaque* settings are activated. One rank could thus be played normally with a slow finger touch, while a fast touch would elicit the unusual sounds programmed with the other dials. One could, for example, program a mutation combination with the *Transposition* dials and play a solo and accompaniment texture on a single manual simply by using a faster touch for the solo line. Or, one could use the *Attaque* dial to program one rank to open only part way when played with a sufficiently fast touch, creating a percussive attack or a wide range of speech characteristics, either alone or at the onset of the second rank's pipes.

This range of timbre all within a single rank would have been impossible with an electric action before the advent of digital proportional valves. The capability to regulate valve depth allows each rank to produce a wide range of speech effects not unlike the transmission ratio and key-depth settings of the Kraul prototypes. In seeking to realize greater sonic potential from each pipe, comparable to the extended performance techniques developed by other instrumentalists and increasingly exploited by composers throughout the 20th century, Kraul's organs in Switzerland and the Modulorgues of Birouste and Fourcade bring new tonal possibilities to the organ in line with the spectral aesthetics of contemporary composers. For instance, the primary reason composer Pierre Boulez has not written for the organ, and continues to refuse to do so, is because of the instrument's lack of touch-controlled timbre and dynamic flexibility.[33] One can only speculate whether this instrument would fulfill Boulez's demands, however it clearly goes a long way toward achieving greater flexibility in some of these parameters.

One additional feature of the Aspiran organ allows a potentially limitless realization of IPC potential. Like the Fokker organ in its recently renovated embodiment, the Mobilorgue operates on MIDI protocol to both send and receive MIDI data. By plugging a computer into the organ one can not only play the instrument directly from software but can also create specialized patches to be activated by the performer. One example that has been used in Aspiran is a flutter-tongue patch. Much like pulling a stop on the console, an organist can reach over to a laptop sitting on the organ and activate a "flutter-tongue stop," causing the valve for each note played on the specified division to continuously and rapidly open and shut for as long as the key is held down. Birouste and Fourcade intend to include

[33] From a conversation with French organist Olivier Latry, November 14, 2010.

this particular patch as a built in stop on additional organs. However, with a little programming ingenuity, one could create any variety of patches to develop new speech and sound effects, or reconfigure how the instrument is played.[34]

Birouste and Fourcade have developed an ambitious and creative business model taking full advantage of the potential that emerges from the combination of Individual Pipe Control with computer assisted performance. The builders have developed a range of Modulorgues, from one to eight moveable divisions, and recently signed a contract for their largest four-manual model. They envision instruments whose tonal specification and layout can be tailored to the widest variety of circumstances, from churches of all sizes to concert halls, public gathering spaces, and outdoor performance amphitheaters. While most organ builders take pride in custom designing every instrument to the exact needs of each client, Birouste and Fourcade appear to advocate a more versatile and economical alternative appropriate for certain public settings. Consideration of the advantages and limitations of each approach is beyond the scope of this paper, but one must admit that no other builder offers entirely mobile organs of comparable scope. Apart from the flexible installation options intrinsic to the Modulorgue's mobility, Birouste and Fourcade also envision greater public outreach by operating the organ through non-keyboard means. One possibility they discuss is a Modulorgue installation where preprogrammed pieces can be "played" by the public using an interactive control station. Tourists could walk up the station, perhaps drop in a coin, select a piece from the menu and use rudimentary controls such as a joystick or motion capture device to control any variety of performance parameters, from tempo to registration.

Birouste and Fourcade's vision clearly defines the organ in the broadest of terms. They certainly do not claim that their instruments are ideal for every purpose, but they could help fill several niches

[34] "Musiques Actuelles," Modulorgue, accessed March 22, 2011, http://www.modulorgue.com/music_actuelle.html.

where the organ is clearly absent from cultural life. One especially radical application of the Modulorgue system advocated by Birouste and Fourcade is unique in the organ world, and perhaps also among the world of acoustic music around the globe. In 2004 Mickaël Fourcade invented a device called "Stido" which effectively interfaces the performer and organ without the necessity of keyboards. Designed as a device for the physically disabled, the Stido allows persons whose physical disabilities prohibit them from playing traditional musical instruments to play the organ using means tailored to their range of motion.

Fourcade has developed sixteen capture devices, measuring input through motion of the limbs and head or air expelled from the lungs. The inputs appear to allow players to have control over certain parameters of preprogrammed pieces, but could also allow for free improvisation and even bottom-up creation of an entire musical composition. In the near future we may be able to dispense with physical gesture-capture devices altogether and develop a direct connection from the electromagnetic clouds emerging from the neuronal networks in a person's brain to the physical mechanics of the organ. Such applications are already being developed to allow, for example, quadriplegic individuals to walk and operate a fully mechanical prosthetic body using only their thoughts – a transformative technology which, according to Miguel Nicolelis, is only four or five years away from fruition.[35]

The kinds of software that allow someone like Stephen Hawking to continue a prolific writing career could similarly allow the most profoundly disabled individuals to compose *and* perform music at the same level as the most experienced able-bodied professionals. Now, with the kinds of technology developed by the Modulorgue team, this reality simply becomes a matter of programming. Such technology has been used for music in the recent past, most notably at the MIT Media Lab under the direction of Tod Machover, to open the doors of music composition and performance to the severely

[35] Miguel Nicolelis, *Beyond boundaries: the New Neuroscience of Connecting Brains with Machines--and How it will Change our Lives* (New York: Times Books, 2011).

disabled.[36] However, these efforts have relied on computer-generated sound. One can hardly imagine what effect playing a powerful fully acoustic pipe organ could have on the psychology of a quadriplegic person, a potentially powerful tool for music therapy research. Through innovative approaches to Individual Pipe Control using new electronic programming and interfacing in conjunction with groundbreaking digital valve technology, Daniel Birouste, Mickaël Fourcade, and the Modulorgue team have developed organs that open up new tonal and expressive possibilities as well as bring the instrument out of the church and into the widest reaches of our culture.

In the first decade of the 21st century, we have already seen an increase in the number and variety of organ-building projects seeking innovative means to achieve new tonal and mechanical flexibility for music of our time. The Modulorgue, Peters Kraul's Prototype III, Peter Bares's organs of St. Peter's Cologne, and the technical renovation of the Fokker organ all occurred within the span of five years. Now, an exciting project in northern Sweden promises to add to this phenomenon. In 2007 the Musikhögskolan i Piteå, the music school of the University of Luleå, opened a state-of-the-art concert hall with world-class acoustics called the Studio Acusticum. One of the central features of the hall was to be a large organ of the highest quality, suited to the musically progressive and technologically engaged vision of the university. Hans-Ola Ericsson, professor of organ at the university, along with an expert group featuring two other organists steeped in contemporary music, Kevin Bowyer and Hampus Lindwall, selected the German firm Woehl Orgelbau to build the new instrument.[37] At the time of writing, the organ case and action had been completed and much of the pipework installed. Installation is to be completed by the end of summer 2011, with voicing taking place over the following year. As construction was in the early stages at time of my research, I cannot relate first-hand

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[36] Adam Boulanger, "Music, Mind, and Health: How Community Change, Diagnosis, and Neuro-Rehabilitation Can Be Targeted During Creative Tasks" (Ph.D. diss., MIT, 2010).

[37] "The Project," The Studio Acusticum organ, accessed March 21, 2011, http://acusticumorgan.com/the-project.

experience of the instrument, but the plans include several highly innovative features that relate to the central topic of this paper. The discussion below is based on interviews I conducted with Professor Ericsson and organ builders Gerald Woehl and son Claudius Woehl in August 2009 and November 2010, respectively.

The concept underlying the Studio Acusticum organ is what Gerald Woehl envisions as the symphonic organ of the 21st century. Drawing upon the symphonic organ traditions of 19th- and 20th-century France and Germany, Woehl has a concrete vision for the new symphonic organ. Such an instrument would compass all of the previous traditions; yet strive neither to be a perfect copy of nor an attempted synthesis of both.[38] He believes that such an organ should use mechanical key, stop, and coupler actions for best control over the wind, though he says electronic aids controlled by sensors may be possible to assist in the heaviest circumstances. Concerning such an assist, Woehl appears to be advocating a device less invasive and more responsive than the electric coupler assists common in many organs today. Additionally, he maintains that the organ should possess a wind system that allows a degree of flexibility, permitting stronger wind in the treble and weaker in the bass to secure the sonority and color of the instrument, much like the divided chests on some Cavaillé-Coll organs.[39] Above all, the new symphonic organ should address music of the 19th and 20th centuries as well as music that is not yet written and not yet imaginable.[40]

The Studio Acusticum organ fulfills this vision through a vast specification drawing upon several symphonic organ traditions, new tonal innovations, and technological applications permitting unparalleled capabilities in an organ of this size. With more than two hundred ranks, it will be by far the largest tracker organ ever built. The vastness of the specification reflects the fact that it represents multiple instruments in one. The four manual divisions include a German Positiv and French Récit as

[38] Gerald Woehl, "Die symphonische Orgel im 21. Jahrhundert," *Musik und Kirche* 74 (2004): 285.
[39] Ibid., 286.
[40] Ibid., 287.

well as a Hauptwerk and Solo with elements of both styles (as well as an English Tuba Mirabilis). The pedal division features a similar abundance of styles, with full German, French, and English reed batteries. In the theater organ tradition, or that of Peter Bares, the organ features at least nine percussion stops in addition to two *Zimbelsternen* and a bird call.

Perhaps the most radical tonal innovation is the inclusion of a floating division called an "Obertonwerk" or "Harmonics Division." Dispensing with inventive mutations and mixtures and highly variable chromatic couplers (examples similar to those discussed on the Bares organs were present in earlier specification plans), the Obertonwerk accomplishes the same ends through new and unique means. Utilizing electric action and situated on a unit chest with one valve per pipe, the division features nearly six octaves of mutation ranks, including more than a three-and-one-half octave chromatic scale comprised of pure overtones.[41] In contrast to the Cymbal mixtures on the Bares Cologne organ, which contained nearly all of the same partials in much smaller quantities, the Obertonwerk allows the performer to choose precisely which partials to add to the musical texture, much like the manipulation of filters in the additive synthesis of electronic music. The tuning of a division as expansively microtonal as the Obertonwerk makes the thirty-one-tone tuning of the Fokker organ look simple in comparison. Additionally, since the whole organ will be tuned in Neidhardt Grosse Stadt temperament, the task of tuning the Obertonwerk will be even more arduous than if it had been equal-tempered, Gerald Woehl attests that it required two months to calculate the precise tunings. The Obertonwerk will initially be purely electronic in order to allow experimentation with the effectiveness of the concept, but plans for a fully acoustic implementation are in the works. In addition to permitting unsurpassed control over the harmonic envelope of the organ sound, allowing spectral compositional possibilities beyond those of even St. Peter's Cologne, the multiplexed design of the chest could allow a

[41] The chromatic scale starting at 4' C, for example, consists of: 4', 3 13/17', 3 5/9', 3 7/19', 3 1/5', 2 10/11', 2 18/23', 2 2/3', 2 14/25', 2 6/13', 2 2/7', and 2 2/15'.

player to reprogram the keyboard to arrange the tones in any order. For example, the Obertonwerk could be programmed to arrange all of the tones in ascending pitch order, allowing a five-octave keyboard to play a span of one octave with more than sixty (unequal) subdivisions.

While the stop specification is readily accessible and can easily be seen to draw from the whole range of the symphonic organ tradition, many of the most original innovations outside of the Obertonwerk can be found in the mechanical and electronic interfacing of the instrument. Eschewing the traditional stop knob, tab, or button array, the console will feature two very large touchscreens on either side, where the attendant stops can be activated. Though the organ contains elements of many symphonic organ styles, stops representing these diverse traditions are not designed to be used together. On the touchscreens one will be able to select the “French” organ, the “German” organ, or preprogram any kind of subset. Additionally, through the touchscreens one will be able to “draw on” any stop to any desired partial length. Partially drawing stops offers fine regulation of tuning, pitch, and voicing and was a popular technique among composers of spectral organ music since the 1960s, including Ligeti, Hambraeus, and Scelsi. With the touchscreens one can partially draw a stop to any one of 128 steps and program it into the combination action. Generating a similar effect across the whole organ or a specific division, several Sperrventilen can likewise be set to open partway and can be adjusted in real time using the touchscreen graphical interface or through the Walze, offering a level of control far beyond the trial and error approximation techniques necessary in traditional mechanical actions.

Though it boasts a massive mechanical action, the organ can also be played remotely, either through integrated recording mechanisms, or by interfacing through any compatible computer. An electric action working in parallel with a fully mechanical stop and coupler action has never been attempted on an organ of this size and complexity. Peter Bengtson, a Swedish software designer, composer, and organist, is carrying out the programming of the instrument’s electronic components.

Recognizing that the MIDI protocol will not offer the speed necessary for seamless manipulation of the sophisticated electro-mechanical interfacing demanded by the touchscreen and remote performance capabilities, Bengtson is building the system around a newer and more flexible protocol called Open Sound Control (OSC). Developed by the CNMAT research center at the University of California, Berkeley, OSC offers a more information-rich and fluid integration between sound and multi-modal hardware and software than the limited, aging MIDI protocol. In taking the unprecedented step of bypassing MIDI and integrating OSC directly into the organ's electro-mechanical action, Bengtson is assuring that the instrument will be able to synergize with state-of-the-art techniques of computer-music composition well into the future.

Remote operation of the organ is possible through a new technology developed by the French Canadian firm NovelOrg Inc. The NovelOrg system uses proportional electromagnetic switches that operate directly on an organ's tracker mechanism. Such "piggy-back" electric action systems have been around for a couple decades, but until now they only offered binary on-off control of the pallet. Like the proportional digital valves of the Modulorgue, the NovelOrg system uses a variable displacement-time function to operate the mechanical tracker action, thus it can accurately record and recreate the subtle haptic control of mechanical action. The NovelOrg system can be used for automatic playback, computer controlled performance of a mechanical organ, or even "virtual" tracker action in a remote division.[42] In the Studio Acusticum organ, the NovelOrg system makes computer operation of the instrument possible, much like the renovated Fokker organ, Modulorgue, and St. Peter's Cologne. As with these organs, this capability makes possible live interplay between human and virtual musicians. Additionally, Bengston is incorporating broadband internet connectivity, allowing the organ to be played from anywhere in the world.

[42] This latter application can be found on the Pasi organ of Sacred Heart Co-Cathedral in Houston, Texas.

The Studio Acusticum organ in Piteå, Sweden embodies Gerald Woehl's vision of a 21st-century symphonic organ. The instrument features a specification drawn from manifold national styles, incorporates a wide selection of percussion stops, includes a groundbreaking Obertonwerk, and integrates the latest technology permitting absolute control over the key and wind action systems from the console or remote sources. The organ's innovative design fulfills Woehl's requirement that the new symphonic organ fulfill the musical aesthetics of today and inspire the as yet unimagined musical ideas of years to come.

Now that we have taken a closer look at some substantial innovations in pipe organ innovation since the Second World War, I will speculate how these developments in microtonal capabilities, spectral flexibility, and console control, in addition to other possible developments, could be applied toward electro-acoustic organ composition. The Fokker organ for the first time allows organists to engage in contemporary movements in microtonal composition. Similarly, through selective programming of the Obertonwerk, the new Woehl organ permits the exploration of any number of microtonal non-equal scales. The Kraul organs, on the other hand, permit real time analog control of microtonal pitch fluctuation.

Through the inclusion of mixtures and mutations and whole divisions featuring radically extended harmonics, in conjunction with diverse percussion and sound effects, the Bares and Woehl organs open up spectral soundscapes far beyond those traditionally associated with the pipe organ. In the Modulorgue, as well as the Fokker, Bares, and Woehl organs, full integration of MIDI or other computer protocols into the action of the instrument allows computer-driven compositions to explore sounds and textures unplayable by direct human control. The Kraul organs offer new multiphonic effects similar to those developed on nearly every other instrument in the 20th century, yet hitherto impossible on the pipe organ.

Advancements in keyboard design and console interfacing allow organists previously unparalleled control over new modes of expression and music-making, including the highly effective keyboard design permitting efficient and virtuosic command of seven-limit just intonation designed by Adriaan Fokker; intuitive button arrays, switches and dials permitting dynamic control of wind pressure on the Bares organ in Cologne; the ability to quickly create novel mixtures and sound combinations on the both the Bares organs and Modulorgue; and the digital control over pipe speech on the Modulorgue. Similarly, the Kraul prototypes offer efficient haptic control of wind pressure, pipe speech and resonance, and pitch and dynamic fluctuation. In addition, such electronic interfacing invites new genres of multi-instrumental or computer collaboration, as well as endless possibilities among new modalities of direct performance by agents removed from the organ keyboards. Advances in this kind of interfacing may hold the key for resurgence in the organ's esteem among art music in the 21st century. Technologies such as NovelOrg, when used in conjunction with a traditional mechanical action or an innovative action of the type found on the Kraul organs, hold tremendous promise by securing the future of expressive mechanical action while permitting myriad possibilities for finely controlled electro-acoustic interfacing of the type found on the purely-electric Modulorgue.

The dramatic advances in the speed and power of personal computing over the past two decades have propelled computer composition featuring live manipulation of performance sound into a principal force in new music. However, the organ's profile among the electro-acoustic composition movement has until now remained minimal. The application of integrated electronic interfacing as I have been discussing, in addition to the inclusion of other electronic components and software, working in conjunction with this new found control over microtonal pitch fluctuation and spectral soundscape could make the organ an ideal vehicle for electro-acoustic composition in the 21st century. In contrast to purely electronic composition or composition for acoustic instruments accompanied by prearranged electronic sounds, the primary interest among contemporary electro-acoustic composers lies in the use of electronics as an extension of the analog acoustic. By putting the human performer in center stage, complete with the requisite human capacity for endless shades of expressive control over an acoustic instrument, composers have found new ways to seamlessly incorporate electronic sounds and real time processing to augment human musical expression. The development of such seamlessly integrated "hyper" instruments has become a major occupation of electro-acoustic composers since early work by Tod Machover and fellow researchers at the MIT Media Lab in the mid 1980s, a development achieved through integrating electronic pickups and controls into the traditional playing techniques of acoustic instruments.

These "hyper" instrumental techniques could be applied to the organ, particularly an organ with extended expressive and spectral capabilities such as those discussed above, to create a musical platform with unprecedented dimensions of electronic control by a single performer. For instance, by building a permanent multi-channel microphone array into the case leading to a bank of XLR outputs, new organs could be built "live-electronics ready" from the ground up. Part of the difficulty of working with live electronics at a traditional organ is that it requires hours of careful microphone placement and testing within the organ case by a team of technicians. A built-in microphone array would allow composers and performers simply to plug in a computer and be ready for live electronic processing. In addition, an organ with two-way MIDI or OSC capability coupled with this sort of plug-and-play microphone array would be able to hook up to a network of other "hyper" instruments for cross-instrumental synthesis. For example, a hypercello and an organ could play with and against each other, with the performance decisions of the cellist effecting the processing and operation of the organ and vice-versa. To aid the discussion I will define an organ featuring all of the following capabilities as an ideal "hyperorgan":

1. integrated two-way computer interfacing protocol such as MIDI or OSC

2. a means for remote control of all performance parameters either through a NovelOrg-type mechanism or digital Modulorgue-type proportional valve technology
3. Built in multi-channel plug-and-play microphone array capable of focusing on distinct subdivisions of the pipework.

Such an instrument would still be capable of playing any traditional repertoire suitable to its tonal design in the usual manner, unencumbered by this additional hardware. In addition, the potential for spectral manipulation through electronic augmentation would be further enhanced through extended analog control over the acoustic properties of the original instrument. Thus, an organ encompassing the microtonal and acoustic-spectral properties as those discussed above would offer the very richest foundation for hyperorgan augmentation.

As we have seen, a hyperorgan would be an ideal vehicle for several electro-acoustic compositional techniques, including the live sound processing and integrated networks of hyper-instruments. The hyperorgan would also make an intriguing platform for DJ sampling compositions. Developing out of the hip-hop culture of the 1990s, a relatively recent group of avant-garde DJ artists, perhaps the best known being Paul D. Miller, a.k.a. DJ Spooky, mix together found fragments of hip -hop beats, works of 20th century composers such as Berio and Scelsi, and speech fragments from well-known poets and authors, including Gertrude Stein and James Joyce. The organ console could be used as a massive mixing device, the keyboards acting as “virtual” turntable manipulators or speech-sample controllers. The organist could also set up loops, creating underlying beats. A single performer building and performing acoustic beat tracks while simultaneously weaving together other musical material and sampled speech could be the start of a new genre of post-hip-hop performance art.

The hyperorgan’s potential is also evident in multi-modal artistic expression, particularly the union of dance and music. Current techniques of dance-music integration typically involve a motion capture device, such as the *Isadora* live video system, to pick-up a dancer’s motions within a predefined expressive space, or use sensors strategically placed on a dancer's body to allow him or her to manipulate or "play" electronic or processed acoustic sounds in real time. Using a hyperorgan, dancers could directly control acoustic sound in a virtual control space. One can imagine a dancer wearing a haptic sleeve, a sleeve with built-in mechanical resistance devices, pulling the air and actually feeling the resistance of the air around the organ pallet. The hyperorgan would open new horizons for such performance media integration. In fact, the Modulorgue and Woehl organ already have all of the necessary hardware to make the above example a reality. This application is also not too far removed from what we have already seen with Mickaël Fourcade's Stido system in conjunction with the hyperorgan capabilities of the Modulorgue. The hyperorgan can be used to allow the physically impaired, children, beginning music students, and the general public play the organ in one way or another. In all of the cases above, the groundbreaking nature of the hyperorgan's capabilities lies in its ability to reclaim for the acoustic that which has until now been the exclusive domain of the electronic, building upon contemporary electro-acoustic composers' increasing focus on the acoustic, analog, or "human" (in the abstract sense) element of musical performance.

One final significant application for this technology can be found in performance research. The hyperorgan can function as a laboratory for research into keyboard psychohaptics, the underlying feedback loop linking music cognition, physical gesture, and acoustic sound production. The integrated electronic interfacing would provide detailed data on speed and timing of key motion, data that could be used for empirical analysis. In addition, through the invention of a keyboard in which the key force-displacement function can be variably mapped onto pallet motion so as to emulate the touch of any characterized organ keyboard, a so-called "haptic keyboard," one can quickly yield research data in a manner that previously would have required significantly more time, travel, and expense. One could obtain similarly interesting findings by applying hyper-organ technology to existing tracker organs with variable transmission ratio and key motion, such as the Kraul prototypes. A field currently in its infancy, the first formal papers in the field are only just now being prepared, and the term “psychohaptics” was coined for this context by Chalmers University professor Mendel Kleiner in August 2009, psychohaptic research would benefit greatly from the all-in-one data collecting capabilities of the hyperorgan.

We have seen how the innovations found in the organs central to this paper’s discussion can be further applied in the service of contemporary electro-acoustic composition. I will now consider what kinds of modifications could be made to an existing instrument to make it compatible with 21st-century electro-acoustic practices. This paper will thus conclude with a brief prospectus for updates to the Kilbourn Hall organ at the Eastman School of Music. This four-manual Skinner organ was completed in 1921 and sits in five concrete fully enclosed chambers three stories above the stage. Originally built with eighty-three registers, sundry percussion, and a coupling and combination action highly sophisticated for its time, it exemplifies the early 20th-century American symphonic organ-building style.[43] In recent decades the instrument has fallen into a state of disrepair; however a restoration project is under way to restore the organ to its original grandeur. With the completion of the restoration, the Eastman School of Music will have a historically significant, large scale organ capable of a wide range of colorful expression situated in the prime real estate of one of the school’s major concert venues. Kilbourn Hall is not only a primary space for solo and small ensemble performances, providing opportunities for the performance of organ chamber or concerto repertoire, the hall is also the principal venue for one of Eastman’s new music ensembles, Ossia, as well as the Composers’ Sinfonietta. As such, the location provides an excellent opportunity to engage composition students and faculty with the organ. While composers could utilize the instrument as is, several modifications could make it more readily compatible with a wider range of contemporary compositional techniques.

[43] Jonathan Ortloff, “The Kilbourn Hall Organ,” in *New Dimensions in Organ Documentation and Conservation, October 11-14, 2007,* by the Eastman Rochester Organ Initiative (Rochester, New York: Eastman School of Music, 2007), 38.

Due to the Skinner organ's historical nature and the painstakingly crafted restoration, any proposed modifications or extensions to the organ would have to be almost entirely non-invasive. As such, the inclusion of some of the innovations discussed above would be out of the question, such as installing proportional digital valves, additional ranks or divisions of high harmonic mutations and mixtures, or mechanical air flow devices for microtonal pitch fluctuation. Thus, while the Kilbourn Hall organ may not exemplify an "ideal" hyperorgan as defined above, a few simple modifications may nonetheless turn the instrument into a potent platform for contemporary electro-acoustic composition. This prospectus focuses on two ideas: the installation of a permanent microphone array within the organ chambers, and the creation of a separate console that can be used in addition to Skinner's original.

Though the organ is under relatively high pressure and voiced quite loud up in the case, the thick walls enclosing each chamber, with heavy wooden shutters in the front, should adequately isolate each division, allowing at least five channels of audio pick-up. In an ideal situation, one would be able to mic each rank of pipes separately. This would permit complete mixing and processing of every sound in the organ. However, ranks situated on the same windchest are too close together for isolation. In my own past experience with live-electronic organ performance, two microphones directed at each division within a widely spaced organ case have proven adequate to permit some degree of isolation, though marked reduction in mic gain was necessary. The architecture of the Skinner Organ, however, provides an ideal setup for divisional isolation without the necessity of reduced gain. Two omnidirectional mics could be installed directly above the pipes in each chamber. Cables could run through the shutter mechanism or chamber access doors and down the wall at either side of the stage, culminating in a fixed panel of XLR jacks at the base of the stage wall or within the stage floor. This would allow direct and immediate access for the composer running a laptop on stage or in the audience. While live-electronic processing represents a major force in contemporary composition, including among the students and faculty of the Eastman Computer Music Center, such compositions for the organ are still relatively rare (they can just about be counted on one hand), owing to the complex, unpredictable, and time-consuming setup at conventional instruments. With a simple, minimally invasive permanent microphone array, Kilbourn Hall could become a model laboratory for live-electronic organ composition.

The Skinner Organ features an electro-pneumatic action wherein the signals from the performer at the console are sent through an electrical umbilical cord to the wind chests in the chambers. The original console features a unique and complex mechanical combination action whose mechanism and wiring comprise an important part of the projected restoration. With the desire to include new operational features, or even a basic solid state memory system, the most practical approach might be to construct an entirely new console. The original console would of course remain a work of immense historical and pedagogical value, but a separate "21st-century" console would open up the possibility for new compositional and performance techniques. The only necessary alteration to the original instrument would be the severing of the umbilical cord for the installation of an electronic switch, permitting one to use whichever console suits the needs of the moment.

The idea of a second "clone" console has long been discussed by some of the Eastman organ students as a means to include solid state memory. However, if one goes so far as to build another console for the instrument, why not include new innovative features impossible or unimaginable in Skinner's time? This could include features considered standard on many new instruments, such as sequencer pistons and a variable crescendo pedal, as well as new features like those on the organs discussed above, such as multiple sustain pedals, chromatic couplers, or a looping mechanism. Most important, I believe, would be to include integrated computer interfacing using MIDI, OSC, or other protocols. This would leave open the possibility for programming as-yet unimagined console control options. In addition, it would allow direct performance of the organ through software or remote means. Using various input devices such as those developed by Fourcade for his Stido system, the organ could be playable in any number of ways by persons with every range of motion limitation.

One more possibility would be to build in a touchscreen system such as that on the Studio Acusticum organ. The touchscreens could act as a laboratory for the development of graphical user interfacing. For instance, an organist could "draw" a function on the screen that would define the parameters of a variable chromatic mixture that fluctuates over the range of the keyboard. The future of graphical interfacing as a means of "sound sculpting" at the organ is an avenue still unexplored and brimming with potential for current movements in sound creation through gestural mapping – again, a movement currently bound by electronic sound-generation that could be opened up to the acoustic.

Informal discussions of some of these ideas with Eastman composition students have generated tremendous enthusiasm. They relish the prospect of being able to compose for the organ in ways that until now have not been possible with acoustic instruments.[44] Through the minimally invasive acts of installing a permanent microphone array and permitting the connection of an alternate console, the Kilbourn Hall Skinner would become a true hyperorgan. Of course, any hyperorgan is only as good as its pipe voicing. In the case of Kilbourn Hall, such a masterpiece of early 20th-century organ-building would become a world-class instrument of the 21st century.

The concept of innovation has been associated with organ-building since the invention of the slider chest. Over the centuries and within diverse national traditions, organ design has continually reflected and affected the musical values of the time. The artistic aesthetics of composers and performers are reflected in the specifications, tonal design, and actions of their organ-building contemporaries. Reciprocally, the aesthetics and innovations of organ builders have shaped the compositional and playing styles of composers and organists. The instruments built and being built by the 20th- and 21st-century organ builders described in this paper exhibit innovative designs that can be

[44] The Disklavier is of course a notable exception as one of the few acoustic instruments completely playable through digital means. However, every composer I've talked to has found the idea of a similar "diskorgan" far more exciting due to the exponentially increased range of sound generation.

utilized to secure the organ's place as a powerful platform for electro-acoustic composition. Adriaan Fokker's 31-note keyboards permit unparalleled command over seven-limit just intonation and other microtonal music. The organs of Peter Bares blend rich mutations, mixtures, and percussion sounds to weave dynamic spectral tapestries. The prototypes developed by Peter Kraul and other builders and researchers permit unprecedented control over the organ's wind dynamics. The Modulorgue of Daniel Birouste and Mickaël Fourcade uses electronic advances to offer new parameters of control over pipe speech and performer interfacing. Gerald Woehl's upcoming Studio Acusticum organ in Piteå will allow an unheard of degree of direct and remote control over mechanical organ action and spectral shaping. Taken together, these innovations pave the way for new "hyperorgan" designs that blend the craftsmanship and tonal ideals of the great organ-building traditions with new means for performance and composition relevant to the multifarious electro-acoustic aesthetics of the new millennium.

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