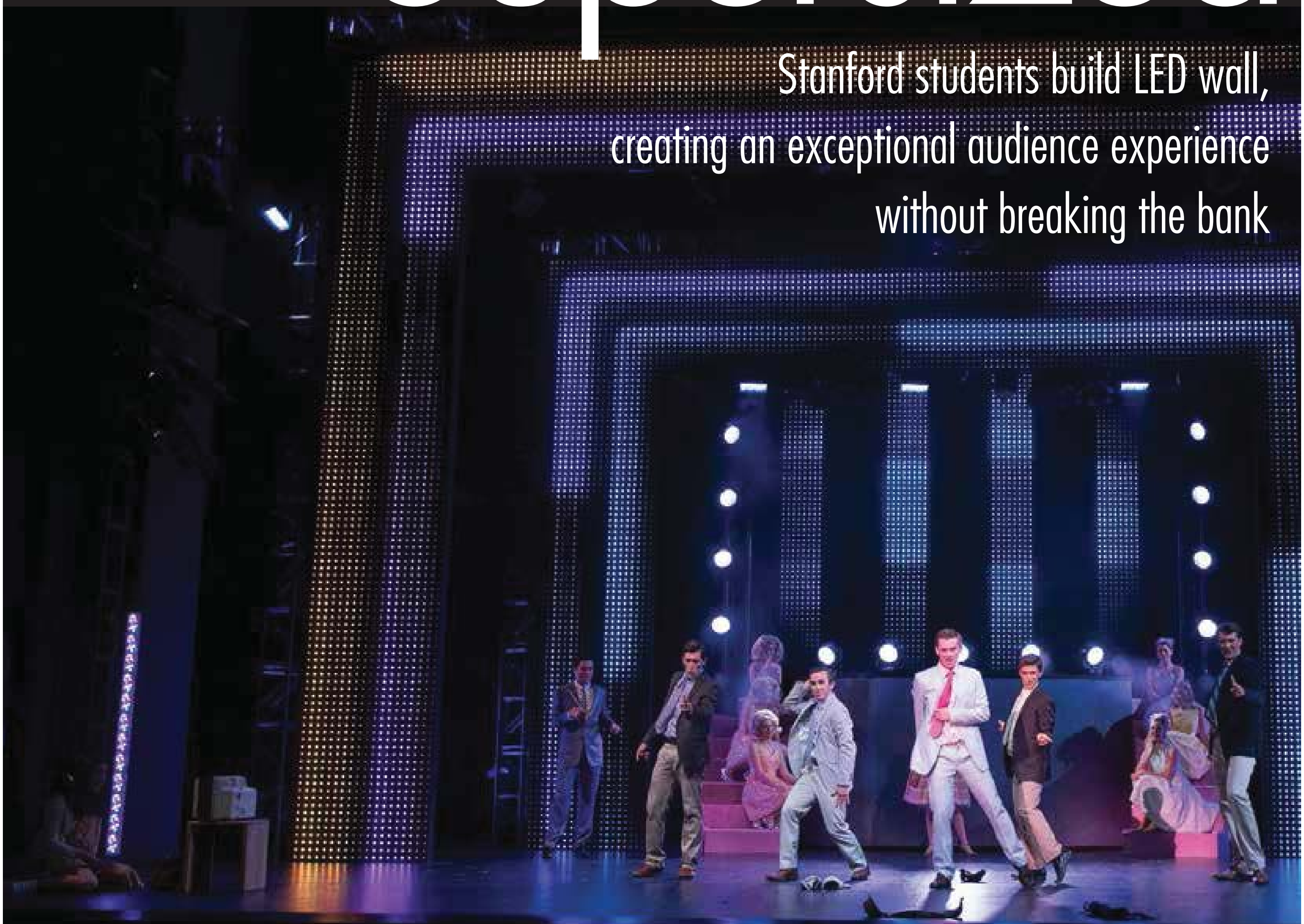
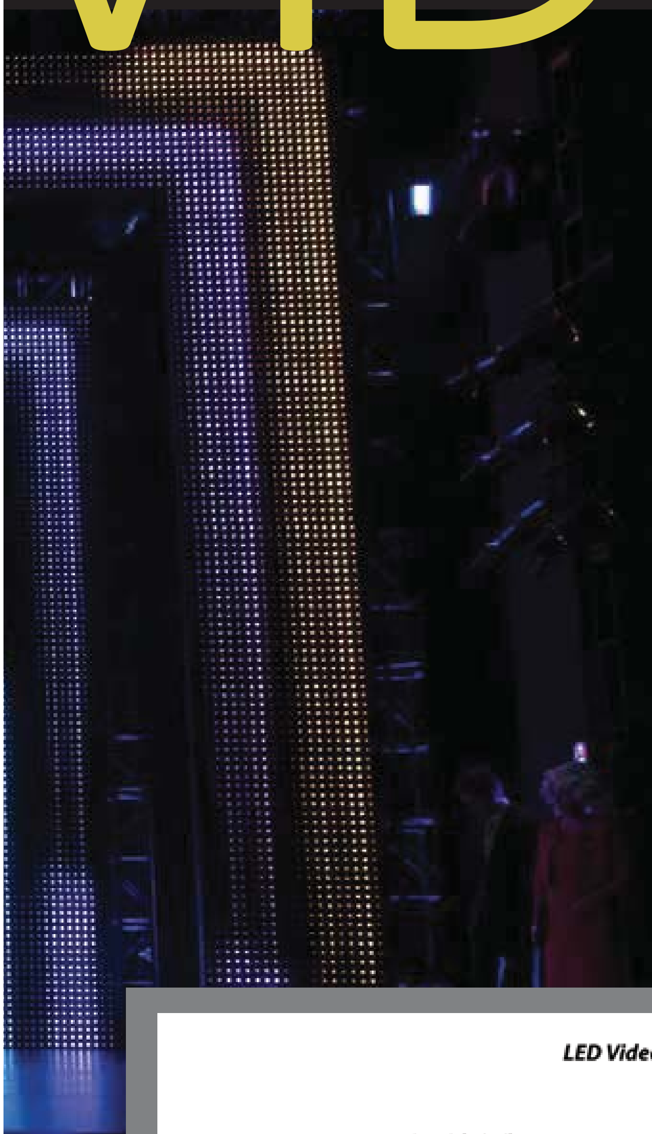
Supersized

Stanford students build LED wall, creating an exceptional audience experience without breaking the bank



The LED wall in use for the number
“It Takes Two.”
Photo by Frank Chen

VIDEO

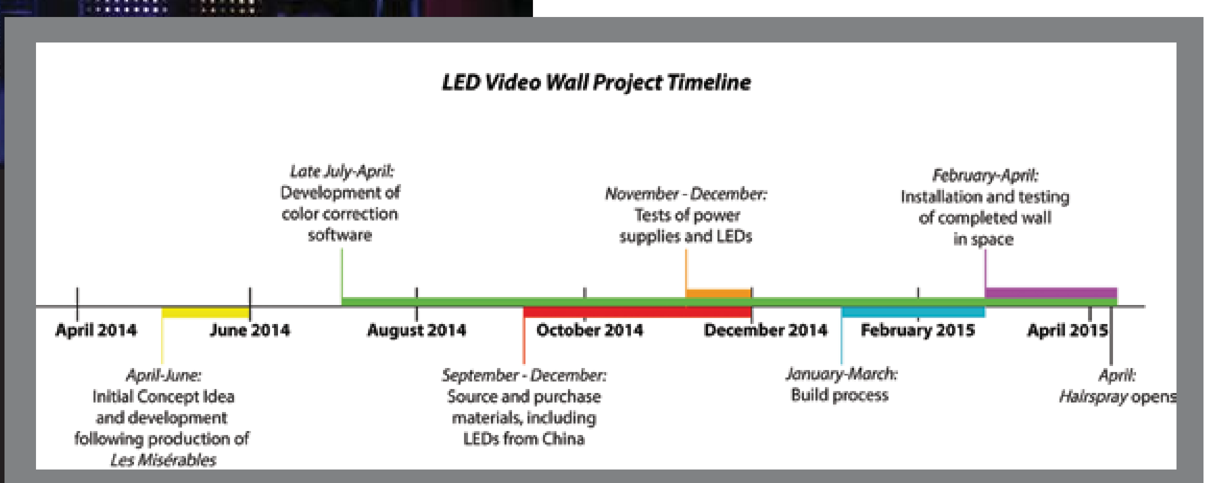


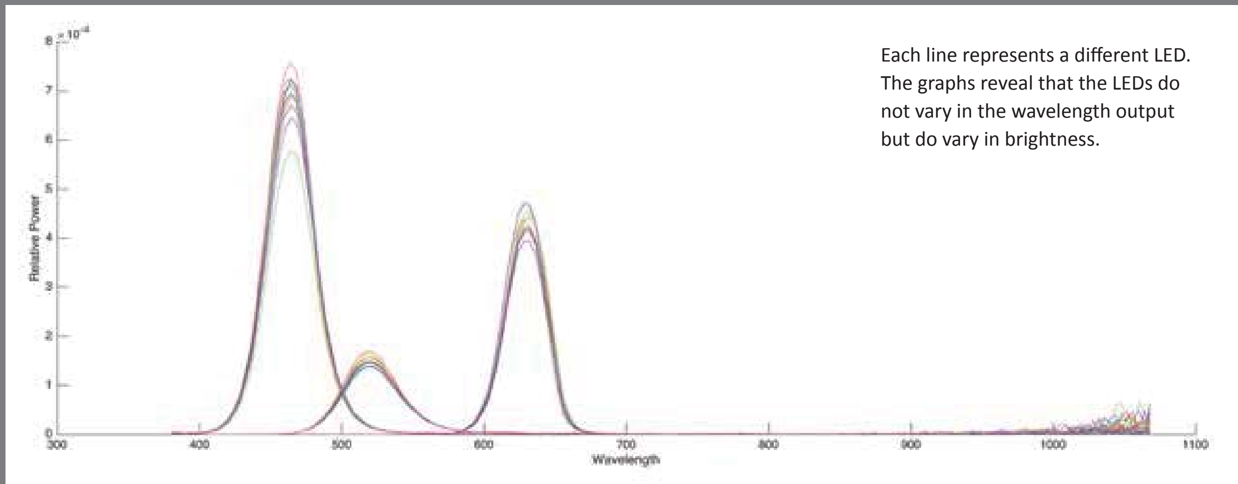
BY STEPHEN HITCHCOCK

PROJECT LEAD & COAUTHOR: MATT LATHROP

At Stanford University, as Ram's Head Theatrical Society's production of *Hairspray* drew closer, rehearsal nights in the theatre grew longer and longer. On stage sat a 20-by-40 foot LED video wall, twinkling like the starry sky. A year after utterly failing to build a star drop out of Christmas lights and vowing not to be bested by hundreds of small plastic caps, the team had built the entire video wall completely from scratch. While this was arguably one of the more expensive solutions to an old school theatre effect, the project had come to be so much more, encompassing the many possibilities and applications of modern LED technology.

Over the previous months, student group Lighting Innovation and Technology Education at Stanford (L.I.T.E.S.) worked to move from research to construction and application, developing an entire suite of software and hardware to realize the goal of a student-built video display. Commercial products of the desired mag-





nitude are phenomenally expensive, and given a modest budget and plenty of free student labor, L.I.T.E.S. was able to make a comparable solution for a mere fraction of the cost. This feat was largely accomplished by finding new ways to correct the inconsistent color of cheap LEDs and designing a distribution system that could efficiently deliver video content.

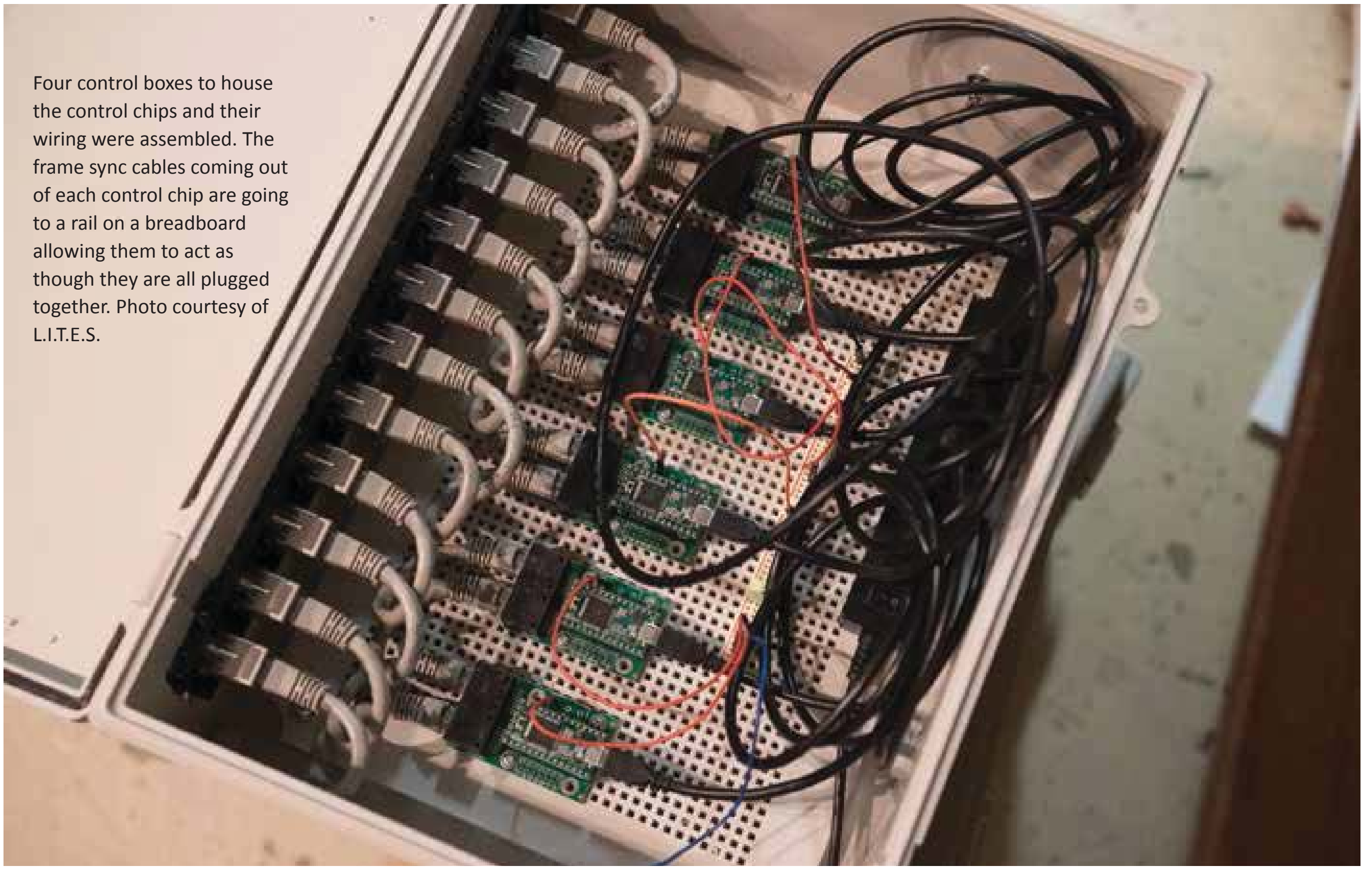
With its upbeat music and constant energy, *Hairspray* provided the perfect platform to test this new, bright technology. Everything about the show screams "big," and "big" was exactly what was needed to showcase this rather physically intimidating product. The team worked to design content that would push the limits of the wall while continually adding to the show experience, all culminating in an extremely successful production that sold out Stanford's Memorial Auditorium.

POWER AND CONTROL

Based on the size of Memorial Auditorium, Stanford's main auditorium where *Hairspray* was to be staged, the team decided to build a 20-by-40-foot wall with 20,000 LEDs. This wall was divided into 50 panels, each a four-foot square and containing 400 LEDs. The display would have a 2.4-inch pitch, or one LED every 2.4 inches. While this may seem large, in reality the low resolution was not an issue once the viewer was far enough away to view the entire wall. With a final budget of around $9,500, funding still would be tight, so the wall had to be constructed economically, yet still appear professional. The goal was to build an inexpensive, professional-looking, modular, reusable, stage filling, and easy-to-use video wall. In other words, an observer of the wall should be unable to tell the difference between this wall and a commercially available LED wall that utilizes color-matched LEDs and has been professionally engineered.

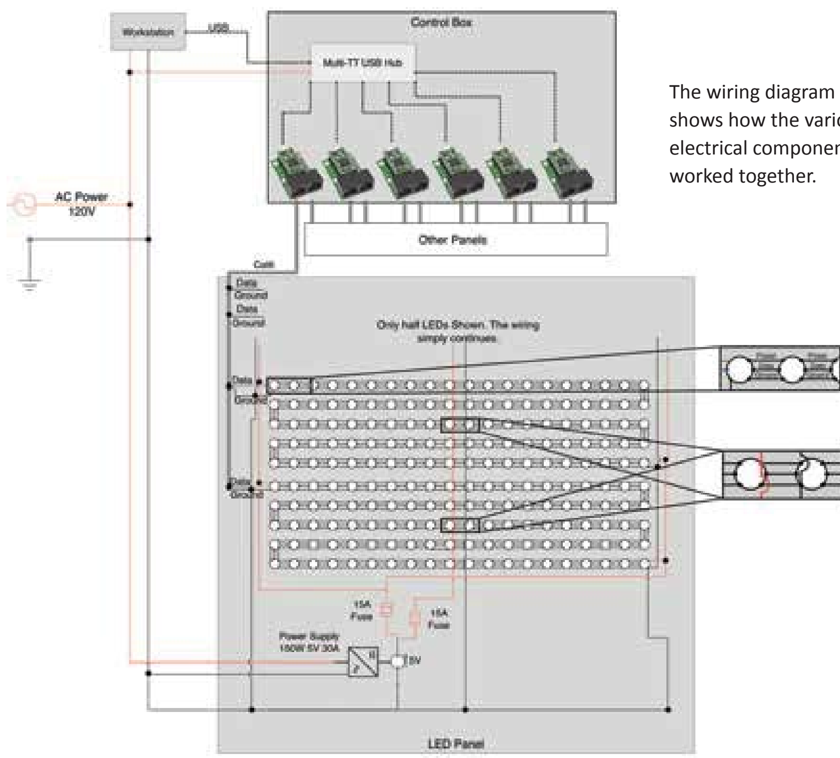
The first step in meeting these goals was to pick materials, beginning with the WS2811 LEDs. These LEDs are inexpensive ($0.16 - $0.22/LED), commonly available, and widely used. The WS2811 LED pixels are not addressed, but instead are identified purely by the order in which they are wired. While the WS2811 LEDs satisfied many important requirements, like almost all LEDs in this price category, they are not manufactured to a high enough quality standard, leading to inconsistent color output. Extra measures would be required to ensure adequate quality.

Because these LEDs update sequentially, and the



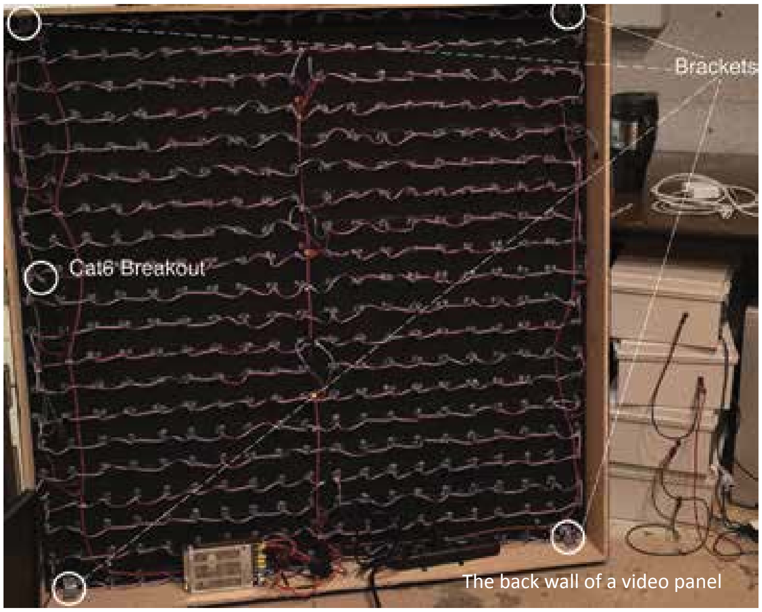
Four control boxes to house the control chips and their wiring were assembled. The frame sync cables coming out of each control chip are going to a rail on a breadboard allowing them to act as though they are all plugged together. Photo courtesy of L.I.T.E.S.

first pixel updates before the last, the team needed a way to update many LEDs in parallel. PJRC's Teensy 3.1 chips and OctoWS2811 adapters solved this issue because each chip has eight separate data outputs. The team used 25 of these chips, one for every two panels, providing four data lines per panel that could all be operated in parallel, eliminating the issue that the LEDs updated sequentially. Of course, because there were multiple chips, all of the chips needed to be synced. This was done with a single wire from each chip connected to a common wire that connected all the chips together. One chip would send out a pulse to tell all other chips to send out their data for a particular video frame. This control architecture was not without problems. In fact, one of the greatest unaddressed problems of the video wall to date is that all the data must be sent from a computer to these chips over USB, which is incredibly inefficient. This issue was circumvented by installing two separate USB chipsets in the computer, but a more complete solution would require moving away from these chips and instead using something like a RaspberryPi. The RaspberryPi chips have more processing power and would allow some intermediate processing on the data; conversely, the Teensy 3.1 chips read data in and then export it in a different format.

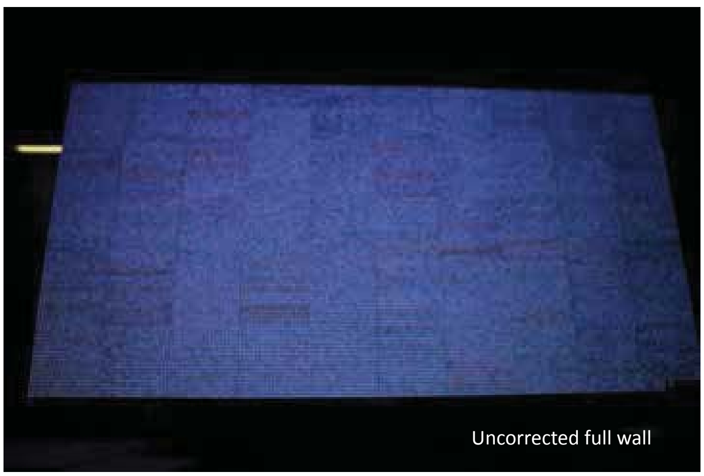


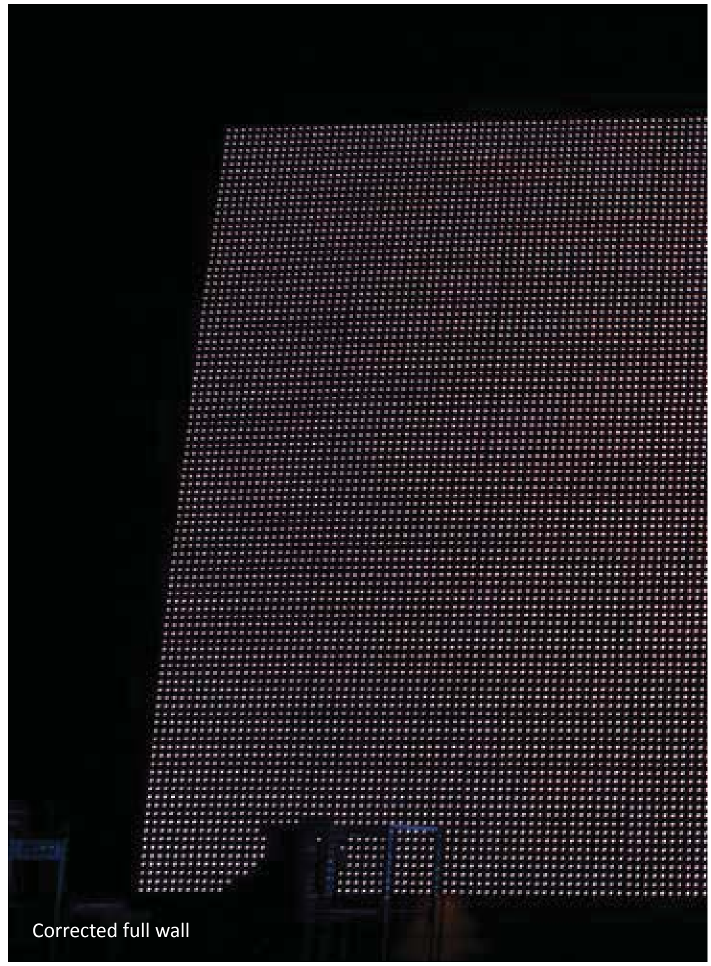
The wiring diagram at left shows how the various electrical components worked together.

DC power supplies were required for the LEDs to function properly. The team chose 5V 150W power supplies because they provided ample power for the LEDs. Operating on a tight budget, the team purchased the least-expensive supplies and, unfortunately, they've had the highest failure rates of any component of the wall, with six failed power supplies to date. This is in stark



The back wall of a video panel


Uncorrected full wall


Corrected full wall

Photos courtesy of L.I.T.E.S.

contrast to the 10 failed LEDs out of the 22,000 ordered.

PHYSICAL CONSTRUCTION

In choosing building materials for the physical panels, the team was highly focused on durability, so the wall could be reused. However, only a small budget remained for building supplies, necessitating the choice of materials that would be widely available and not require specialized knowledge or tools for repairs. Based on the project's needs and the budget, the team chose wood as the primary building material. To add structure, metal brackets held the wooden frame of the panel to the plywood.

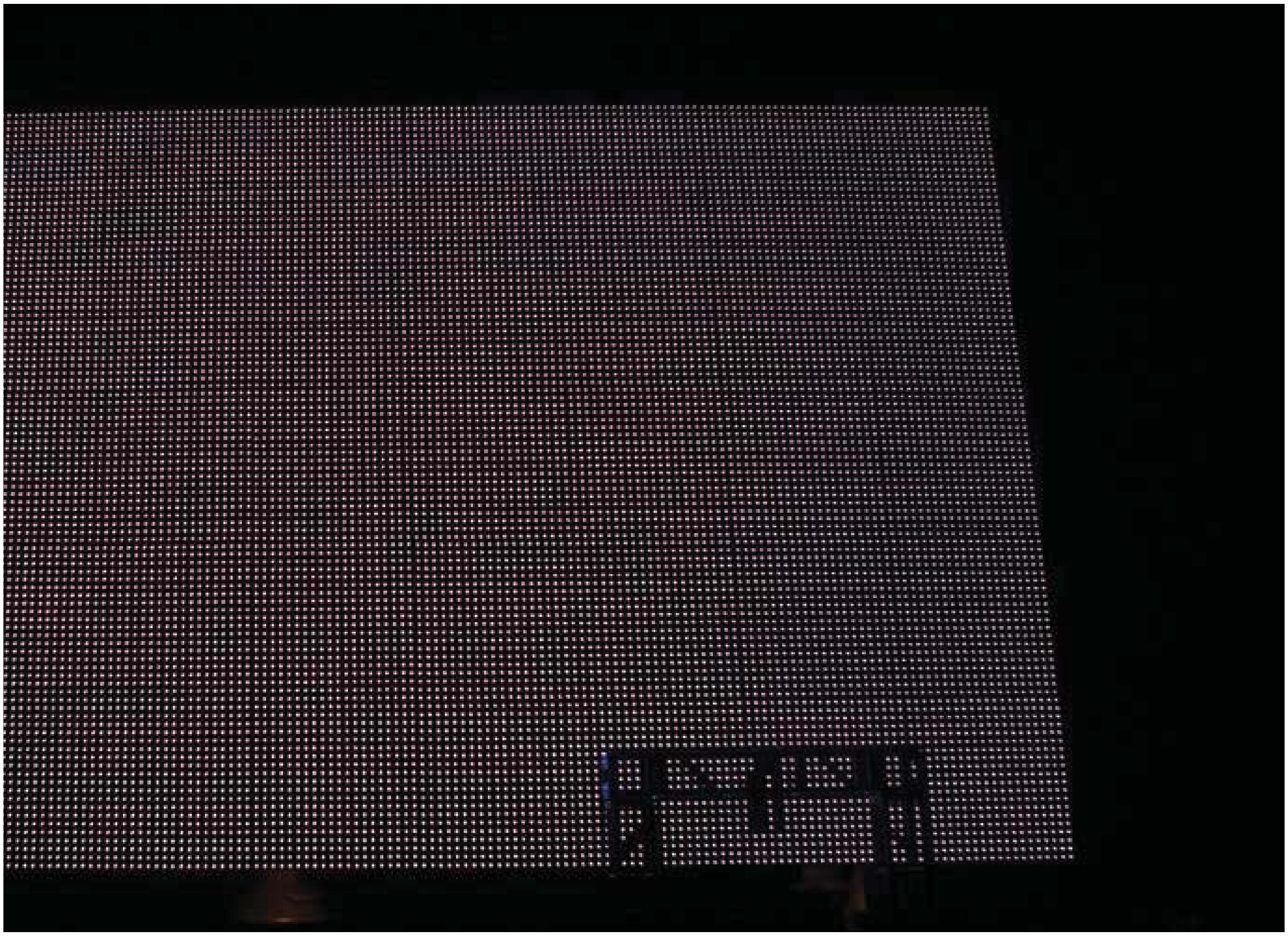
The image showing the back wall of the video panel (above) also shows some of the other build choices, such as the decision to use hot glue to hold the LEDs to the panel. This allowed for quick replacement of broken LEDs and kept LEDs from unintentionally falling out.

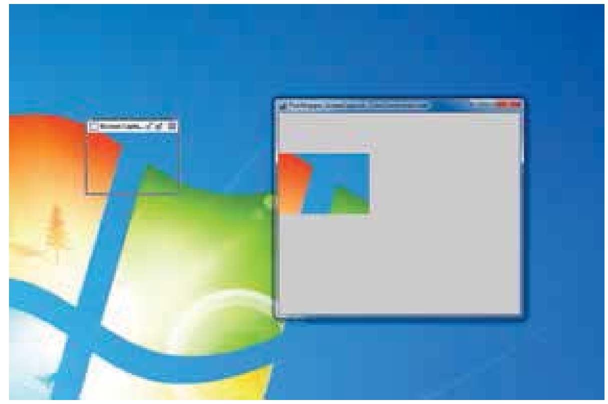
The team constructed and assembled the wall over a period of five weeks. The first step in the construction process was to make the faces of the panels. The faces were made of 3/4-inch plywood. After all of the faces were cut, the long and tedious part of the construction began—drilling the holes for the LEDs, gluing them into place, adding structure to the faces, and then, finally, completing all of the wiring for power and data.

COLOR CORRECTION

After the wall was constructed, making it appear as professional as possible became the challenge. While the wall looked uniform in deep saturated colors, it looked inconsistent when set to white or other non-primary colors. This is largely because to produce white and intermediate colors, these LEDs had to mix their red, green, and blue sub-pixels. These sub-pixels differ in output brightness from LED pixel to LED pixel as can be seen in the image (above left).

To address the need for consistent color on the wall, the team developed a color matching technology making it possible to simply image the panels producing the three primary colors (red, green, blue) with a camera, read the intensity each LED was producing in each color, and then adjust that intensity to be the same as the least bright LED in the video wall. Working from the least bright LED was necessary because, while it is easy to make an LED less bright by setting its intensity value lower, there is no good way to make an LED brighter than full brightness. The results of this correction can be seen in the image (above).





The capture interface for the LED wall software is pictured above. Whatever the window is placed over is sent to the video wall.

Once all the LEDs looked the same and were producing the same color, the next step in the process was to make the colors that the LEDs outputted match the computer monitor. This was accomplished by taking color spectrometer readings of an “average” LED pixel and then mapping the color it outputted to the sRGB color space used on most computer monitors. *(Get more details about the color correction at http://lites.stanford.edu.)*

Finally, after the wall looked professional, the project’s focus shifted to making the wall work in the context of a show. The solution was to create a way to capture content and send it to the Teensy chips in a format they could process and understand. To keep the process for getting content from a computer screen to the video wall as straightforward as possible, a piece of software was designed to capture a region of the computer screen and output that region to the video wall.

This interface meant the procedure would be compatible with virtually any method of playing back video content—from PowerPoint to WATCHOUT. Next, the focus shifted to the actual content for the show.

CREATING FOR A MUSICAL

The world of *Hairspray* balances the height of 1950s consumerism against the African American struggle for equality. The bright, bombastic world of the Corny Collins Show, a caricature of a late 50s television show, stands in sharp contrast to the poverty on the other side of town. While the need arises for two distinct realities, the true beauty of the show shines through as these worlds meld together, providing both comedic and touching moments.

Staging these concepts required a mix of both period and modern content. An examination of the overdone sets of real 1950s television shows and their distinct affinity for geometric shapes and pastel colors provided the period content. On the modern side, inspiration came from contemporary dance and competition shows like *Dancing with the Stars* with their air

Locational video content from "The Madison," designed to evoke a high school dance
Photo by Frank Chen

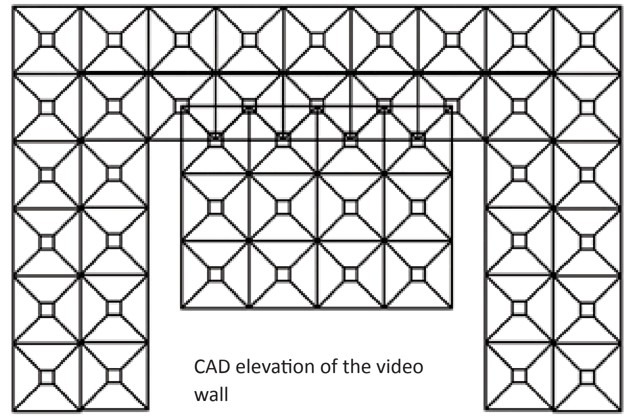
Concept art for "Good Morning Baltimore."
Photo courtesy of L.I.T.E.S.

Testing production content for Hairspray on the LED wall. Photo courtesy of L.I.T.E.S.

of sophistication. The designs were born somewhere between the two, with enough sophistication for visual excitement, while maintaining all the gaudy energy of the period.

- **Realistic vs. Supportive.** To equally serve the design aesthetic and the limits of the technology, all of the content would have to avoid literal depictions. At a resolution of only 180 x 120 pixels, it's extremely difficult to portray anything as photorealistic. The team spent an entire day watching movie trailers on the testing configuration to determine what types of content read easily. Thanks to its bright colors and clear outlines—two features normally missing from live action footage—stylized animation was the clear winner. Using the wall as a live feed was also ruled out for similar reasons, which were further compounded by video delay.
- **Locational vs. Dynamic Content.** Accepting that every scene needed to be carefully designed for these parameters, the team began creating concepts that sought to support the essence of their real-world foundations instead of directly mimicking them. Two distinct categories of content were emerging: designs that aimed to establish a particular physical location and designs that aimed to dynamically reinforce the mood of the action. Generally, these fell along the lines of scenes and songs. Much like lighting design, the video wall provided scenes with a location like a gym, Tracy's house, or the record shop. These concepts were mostly static, but just like light cueing for most modern musicals, songs attract a more dynamic approach. These designs aimed to enhance the music by providing

Dynamic video content for “Baltimore Crabs”



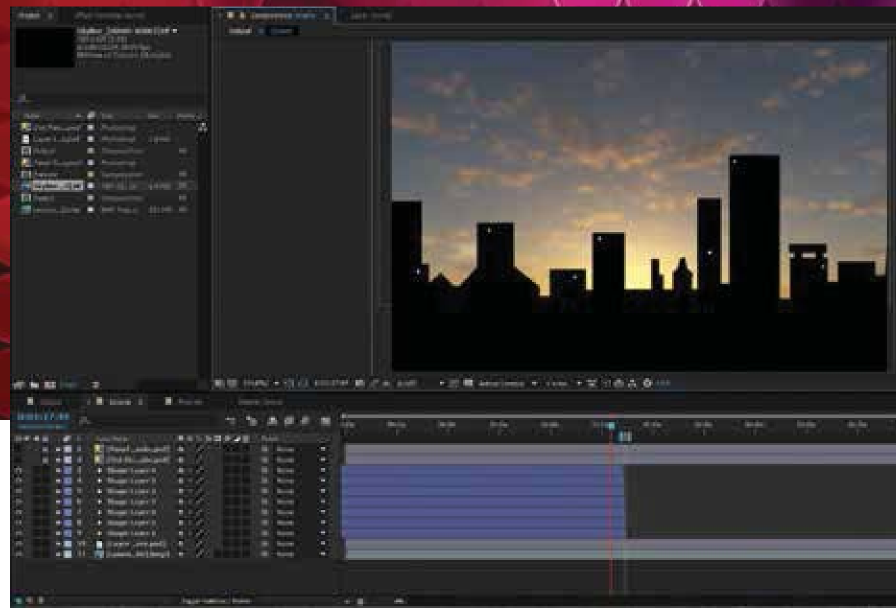
CAD elevation of the video wall

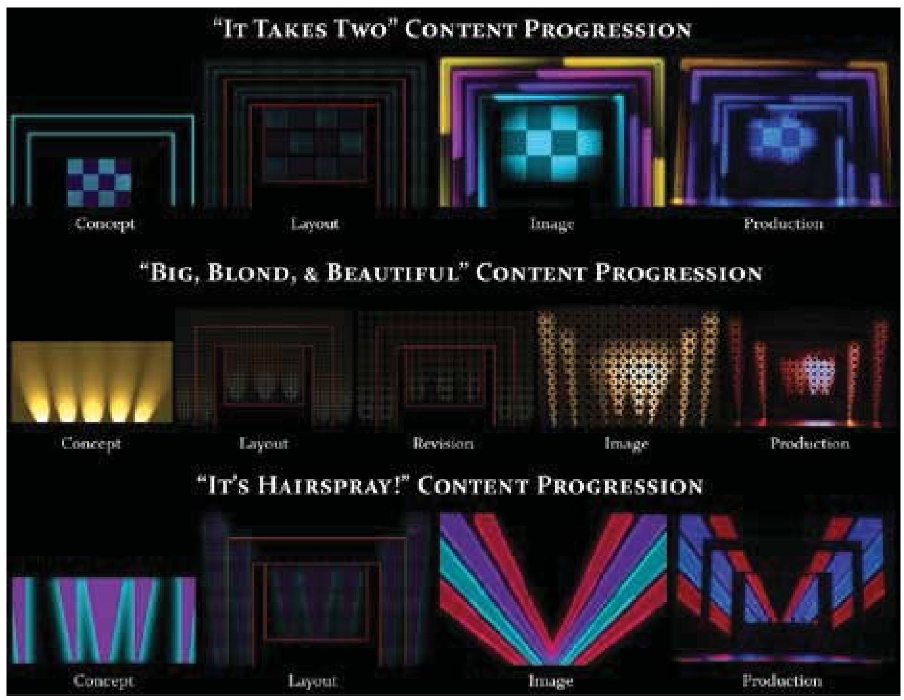
movement synchronized to the score. In one concept, a graphic visualizer pulsated with the dance choreography. In another, a twinkling star drop accented a love song. While, in hindsight, both types of content are clearly unique, it took similar effort to bring all designs from concept to a working prototype.

- **Theatre Design and Physical Setup.** Some concepts started from a distinct idea, like a jukebox to complement a *Jersey Boys*-esque serenade. Others started from abstract patterns found on purses and lighting gobos. But all of these ideas underwent lengthy processes of development governed by the show aesthetic and physical feasibility. One of the first challenges tackled in collaboration with the set designer was integrating the wall into the set. After discussing ideas that ranged from triangular walls to curved edging, the team arrived at the concept of portals. The panels would be divided into three distinct groups that would form progressively shrinking portals over the stage. The first two portals would stack single panels as legs up each side of the proscenium, connected by a single row of panels at the top. The third would be a solid wall at the back, created with an array of four-by-four-foot panels. The next step was to refine the earlier concepts to fit this physical constraint. With the largest portal measuring nine panels wide, everything was designed at a resolution of 180 by 120 pixels (each individual panel consisted of 20 by 20 pixels). Some designs treated each portal uniquely while others flowed seamlessly between surfaces. Though large areas in the center of the design went unused due to the spacing of the portals, it was easiest to create a single image for all portals to serve both styles of designs.
- **Content Testing Tools.** Due to the disjointed nature of the portals and the separation of pixels on each panel, the team quickly realized the need to visualize the designs

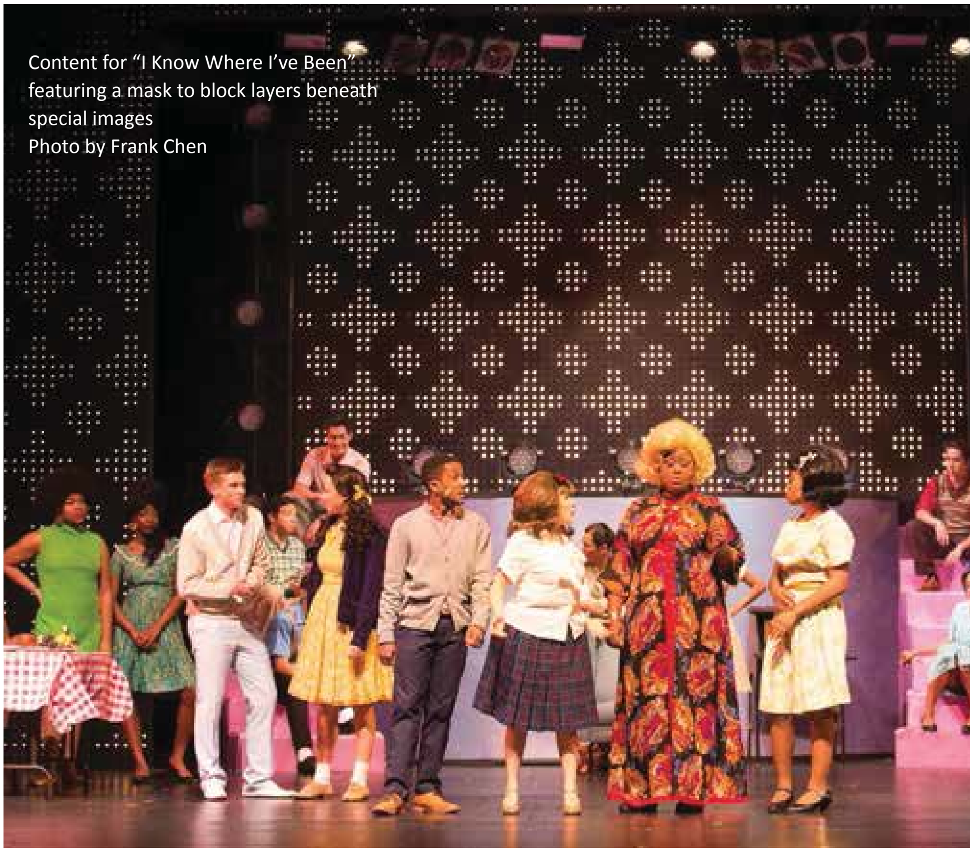
before the video wall was set up in the performance space. Using CAD drawings from panel construction, one team member developed a mask that could be overlaid in a compositing program like Adobe Photoshop or After Effects. By only letting the underlying design shine through in distinctive, small points, the mask provided valuable insight into how an image would look in space. The team also conducted experiments with other, more complex simulations of the wall. For example, the team constructed a complete mockup of the set in Cast Software's WYSIWYG and fed video clips and images of designs. While this method was effective and certainly more realistic, the simplicity of the mask made it the go-to tool, allowing its use in whatever software package was being used instead of exporting a preview.

- **In-Space Challenges.** Once the wall was physically constructed, it became clear that not all of the designs would transfer seamlessly from concept to product. With some ideas, the evolution was straightforward. For example, the jukebox for "It Takes Two" easily transitioned from a rough image to a final design with only minor adjustments. Other concepts, like the rays of light for "Big, Blond, and Beautiful," stayed the same in spirit, but had to be restructured to line up with the portals. Finally, some concepts were just beyond saving. At one point, the director remarked that the initial concept of "It's Hairspray" looked like pairs of legs. In that rare case, the concept was completely rebuilt from the ground up, creating a design that accomplished the same purpose but in a completely different way. But like the rest of the problems, the team pushed through with the limited time. The key became keeping everything organized as deadlines started approaching.
- **Media for the Unpredictable.** Given the limited time available to access the performance space and the need to keep the designs constantly editable, the team needed to invest significant thought into how media was created and stored. The bulk of the design work took place in Adobe After Effects, which operates by separating media, such as images, videos, or dynamic effects, into distinct layers to form a single image. For example, the opening number of the show consisted of nine distinct layers: a video of a sunrise, a city skyline, and squares meant to represent lights in offices. Some designs were built from upwards of 50 layers while others utilized two or three. Most of the static content, like the skyline, was built in Adobe Photoshop, which is more suited to simple image manipulation. More complex designs that involved 3D

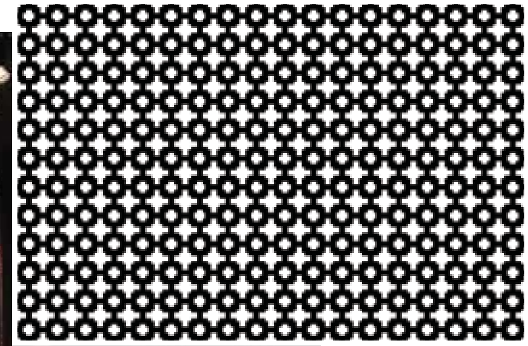




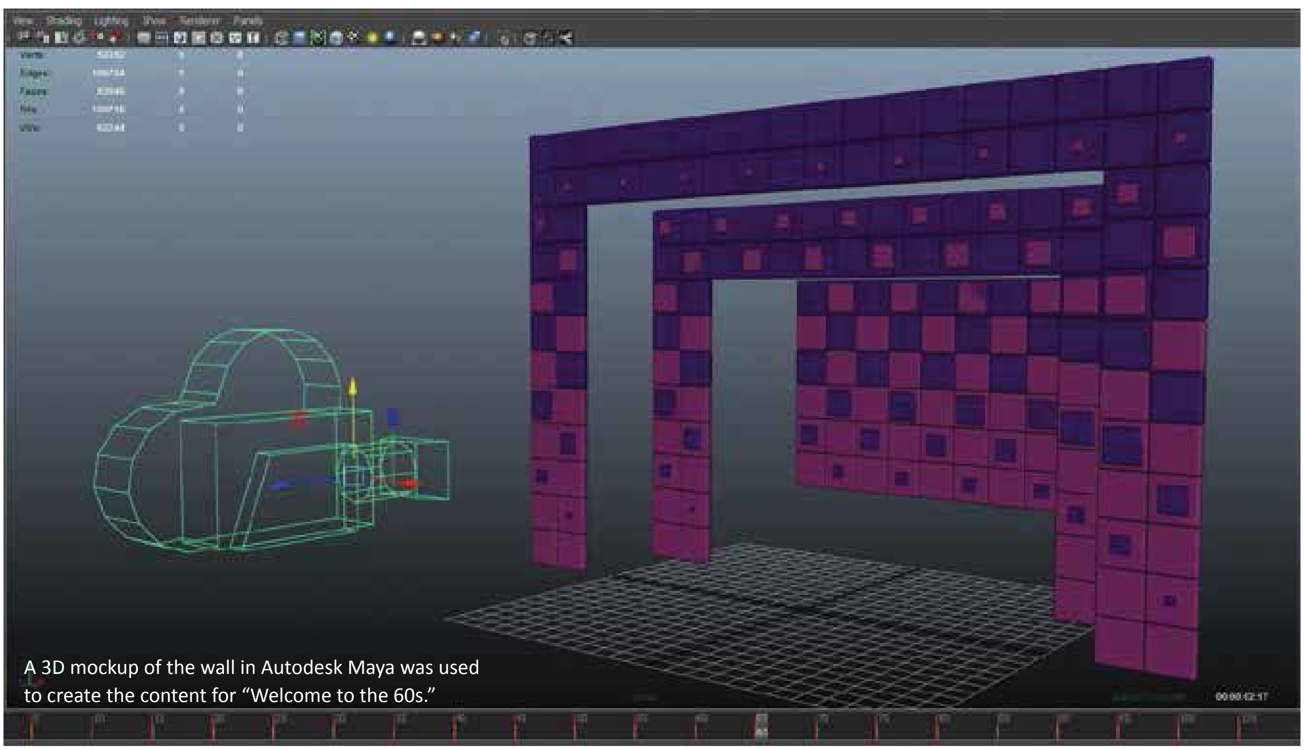
The top image shows multiple layers that were used in "Good Morning Baltimore." The bottom image depicts the development process of several musical numbers.



Content for "I Know Where I've Been" featuring a mask to block layers beneath special images
Photo by Frank Chen



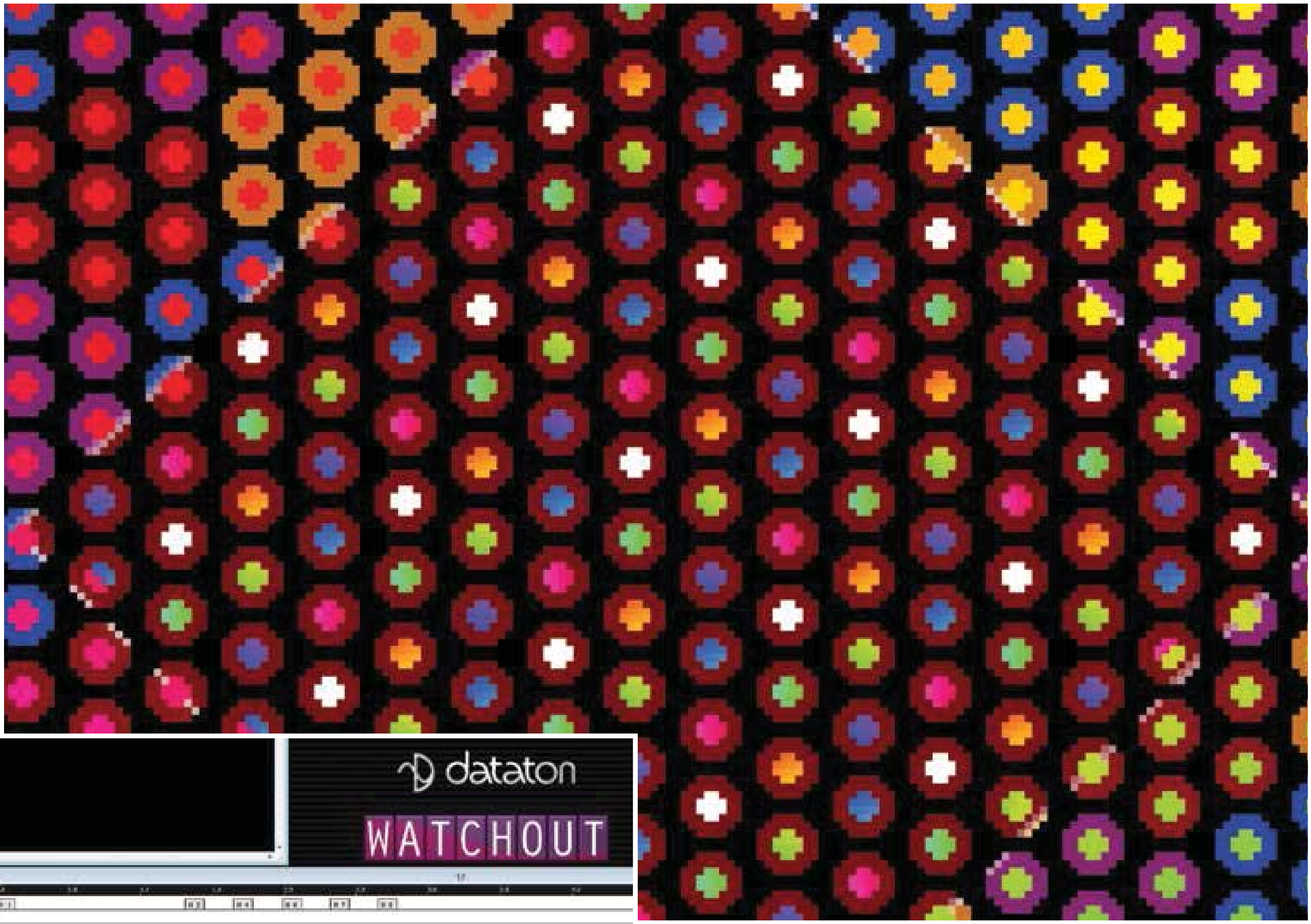
An example of a mask



A 3D mockup of the wall in Autodesk Maya was used to create the content for "Welcome to the 60s."

elements were built in Autodesk Maya. For example, a design that flipped dozens of squares in time with the music would have been particularly cumbersome to animate in a two-dimensional software package. In Maya, users can keyframe objects to move in 3D space, a feature that was utilized in several designs. Items built in Maya have to be rendered—that is, converted from 3D animation into a series of still images. For the process, the team utilized Pixar's RenderMan and imported the final images into the After Effects compositions as an individual layer. Because the process of rendering is generally time consuming, the team used bright, distinctive colors that were completely unrelated to those used in the design. That way, a sequence could be easily repurposed to play with different colors by telling After Effects to replace a given color in the render with one of the initial choices. This also became vital to the overall design process, as the team found that often the initial color choices were ill suited to the LED's color rendering. Masks become another media element central to the designs. In testing, many of the concepts lacked contrast and were simply too bright for comfortable viewing. To alleviate such strain, special images that are either black or transparent were used to block layers beneath them. This successfully created regions of darkness in the image, addressing concerns and helping the image appear more interesting.

- **Asset Management.** With so many media elements making up each design, it was crucial to develop a system to organize and quickly access each element used in a composition. By creating a file structure, each design could be separated into an individual folder with its corresponding After Effects project. All dependent media, which included both initial concepts as well as reference masks and external images, were stored in these folders. During tech, the team could then modify individual files as necessary, and the After Effects project would automatically reflect such changes.
- **Live Compositing.** Keeping the media flexible was the most significant challenge experienced across all content design. At any time, the team needed the ability to make quick changes to an item's color, brightness, and screen position. While all of these are easy to address in After Effects, this flexibility would be needed in WATCHOUT for final tech and performances. Timing was the more significant property needing constant adjustment. Many designs worked dynamically with actions on the stage, whether blocking or musical cues. Due to the nature of live performance, the tempo of the music, delivery of lines, and choreography are constantly shifting and can rarely be relied upon for consistency. While it is easy to build cues in WATCHOUT much like those you would find in Figure 53's QLab or on a lighting console, difficulty arises when you only want part of the image to be modified by a particular cue. For example, in the final number of the show, the team had dots that consisted of an inner and outer color. The inner color looped through a continual Hue/Sat fade, while the outer color largely remained constant. However, on certain musical beats, the team wanted groupings of outer colors to change, creating a flower-like pattern. The challenge was to devise a way to alter the outer content without resetting the ongoing Hue/Sat fade on the inner dots. The solution was to individually export each layer of animation created in After Effects as a separate file to be imported and re-composited in WATCHOUT. This way, it was possible to adjust basic parameters like color and intensity but also loop individual animations independently of each other. In the



The video content for "You Can't Stop the Beat," which was composed of many distinct layers

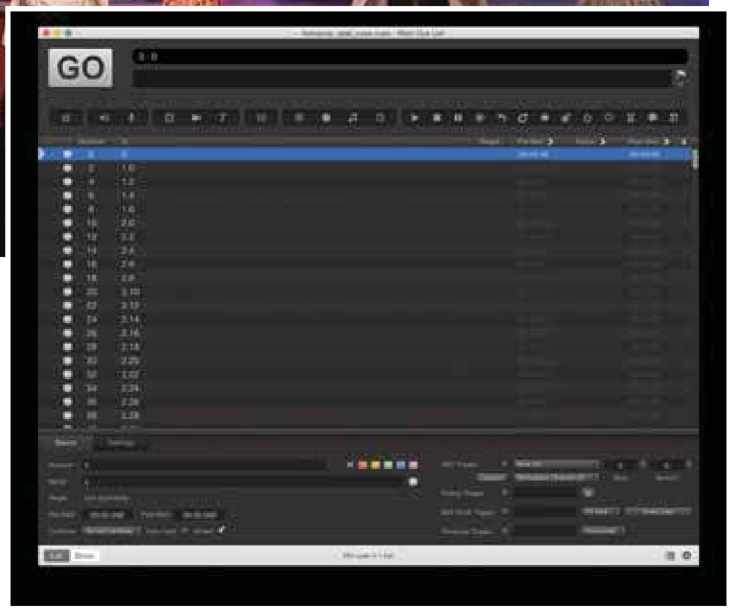
The different layers for "You Can't Stop the Beat" loaded and sequenced in WATCHOUT

example of the finale, the inner and outer layers were separated to allow for different timing.

- **Live Final Equipment Setup.** Once the team chose solutions for show control and finalized the software for outputting images to the wall, it was important to finalize the pipeline to ensure that the media worked consistently during performances. Rather late in testing, the team discovered that most professional projection software packages, like WATCHOUT, attempt to take control of the screen they output to. In most show contexts, this is a good thing, because it prevents other background software from accidentally displaying itself on the projectors. However, in this project, a screen capture system took a portion of the computer display and output it to the video wall, creating a conflict between WATCHOUT and the system. Furthermore, this project needed to run the content from the tech booth, but the computer running the video wall was located back stage. The 11th-hour solution was to take advantage of WATCHOUT's implementation of Midi Show Control, running MSC cues from QLab and capturing the image on WATCHOUT's content designer interface. While this solution created a host of problems, namely from the inability to monitor the WATCHOUT timeline, it ended up working well enough for the relatively short performance run.
- **Cue Calling.** Another unexpected problem that arose during final dress rehearsals was the ability of the stage manager to call the nearly 300 video cues on top of the 400 lighting cues. Because there was surprisingly little overlap between video and lighting cue timing, it became all but impossible for the Stage Manager to successfully call the show. As a result, the video content designer stepped in to specifically time the video cues for performances, leaving the stage manager with a more realistic workload.

In the end, the production of *Hairspray* was extremely successful due in no small part to the LED video wall. From initial concepts to final performances, the design process spanned approximately three months

The cast of *Hairspray* with the video wall in the background
Photo by Frank Chen.



The QLab cue list used to remotely control WATCHOUT

and produced almost 14,000 individual files.

Although the production created many unique challenges, each requiring creative solutions, the team successfully overcame many technological, design, and time constraints. By creating a consistent process for visualizing designs and a uniform production pipeline for delivering media, the team balanced the scope and scale of the design with the realities of deadlines and physical constraints.

Plans moving forward include spending more time refining the process of tightly integrating large-scale media into major productions. Looking at how to employ the video wall in different scales and physical setups that can be catered to individual shows, all while maintaining the flexibility and media pipeline developed for *Hairspray*, will be the next challenge.

Note: WATCHOUT was donated for use on the show by Show Sage. The authors also wish to thank the members of L.I.T.E.S. and the faculty and staff at Stanford who made this project possible.

Matt Lathrop is a graduate of Stanford University where he studied computer science and lighting design. He has conducted two major research projects bringing together computer science and lighting design while at Stanford, the first of which was the Remote Controlled Follow Spots project published in TD&T *Winter 2015.*

Stephen Hitchcock is a sophomore at Stanford University studying Computer Science and Lighting Design. He is passionate about combining art with technology, and is currently researching new methods for heavily integrated show control systems.