The aesthetics of infrastructure: reflections on the scale models of the TVA

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ABSTRACT: Recognizing the importance of aesthetics in the contemporary discussion on infrastructure design, this paper looks to the work of Tennessee Valley Authority (TVA) as a historical case study that successfully merged a strong aesthetic agenda within an infrastructure project. The structures of the TVA have been extensively published in architectural journals and popular magazines for their innovation in dam design, modern appearance and ability to incorporate humanist values within a large-scale infrastructure project. Often discussed through the grand vision of the Chief Architect, Roland A. Wank, less attention has been focused on the specific project methods utilized in the collaboration of the architects and engineers of the TVA. With research collected from the National Archive at Atlanta, this paper explores the role that scale models play in the design process of the TVA during the design and construction of Norris Dam. For architects, the scale model is an important tool for the testing and communicating a project's design intentions. However as is common in the world of architecture, the model is more than a utilitarian tool, often gaining the status of an aesthetic object that exists in its own right outside of the project for which it was intended to describe. While the production and reception of architecture models comes with its own extensive history and theorization, this paper looks specifically at the models that were built for a large-scale infrastructure as the site in which an aesthetic project that could be initiated by the architect is adopted within the working process of a large collaborative design team.

KEYWORDS: Architecture, Infrastructure, Aesthetics, Representation

INTRODUCTION

In 2017, the American Society of Civil Engineers "Infrastructure Report Card" scored the United States overall infrastructure a grade of D+. The overall score reflects that the

> "infrastructure is in poor to fair condition and mostly below standard, with many elements approaching the end of their service life. A large portion of the system exhibits significant deterioration. Condition and capacity are of serious concern with strong risk of failure." (American Society of Civil Engineers 2017)

The report calls attention to the large quantity of projects that will be required to maintain the current infrastructure in place, as well as to improve the quality of design for the health and well-being of future generations.

The topic of infrastructure design has also been gaining attention in the architecture community as exemplified by international competitions for signature landscape urbanism projects such as the Highline, Freshkills Park and Downsview Park, bridge designs coming out of offices like OMA, Michael Maltzan and Santiago Calatrava, and even academic design speculation from smaller practices such as Urban Lab, Lateral Office, and The Office for Political Innovation. The buzzing of design activity by architects within the field of infrastructure combined with the national crisis of the state of contemporary infrastructure as declared by the ASCE appears to provide an opportune moment for architectural speculation to engage a 'real-world' design problem.

Recognizing the importance of aesthetics in the contemporary discussion on infrastructure design, this paper looks to the work of Tennessee Valley Authority (TVA) as a historical case study that successfully merged a strong aesthetic agenda within an infrastructure project. The Tennessee Valley Authority Act, signed in 1933, formed the TVA and initiated one of the largest infrastructure projects in the history of the United States. The TVA projects transformed the terrain of the Tennessee Valley and surrounding region through the construction of hydroelectric dams along the Tennessee River system. The dams themselves were designed to produce hydroelectric power, control soil erosion, improve land productivity and increase recreational opportunities. The initial 16 dams were designed and constructed by a team of architects and engineers between 1933 and 1944.

The structures of the TVA have been extensively published in architectural journals and popular magazines for their innovation in dam design, modern appearance and ability to incorporate humanist values within a large-scale infrastructure project. The structures have also been praised for the ability to exemplify a harmonious union between architecture and engineering, demonstrating both aesthetic sensibility and technological performance. Often discussed through the grand vision of the Chief Architect, Roland A. Wank, less attention has been focused on the specific project methods utilized in the collaboration of the architects and engineers of the TVA.

This paper explores the role that scale models play in the design process of the Tennessee Valley Authority during the design and construction of Norris Dam. For architects, the scale model is an important tool for the testing and communicating a project's design intentions. However as is common in the world of architecture, the model is more than a utilitarian tool, often gaining the status of an aesthetic object that exists in its own right outside of the project for which it was intended to describe. While the production and reception of architecture models comes with its own extensive history and theorization, this paper looks specifically at the models that were built for a large-scale infrastructure as the site in which an aesthetic project that could be initiated by the architect is adopted within the working process of a large collaborative design team.

1.0 THE NORRIS PROJECT

Beginning as early as 1911, the site of Norris Dam was examined as a potential location for hydro-power. The Norris Dam site is located on the Clinch River a tributary of the Tennessee River. In 1922, a formal study was conducted by the US Army Corp of Engineers of the Tennessee River Valley which recommended a series of dams along the Tennessee River and its tributaries, including one at the future site of Norris Dam then referred to as the Cove Creek site. Interest in the Cove Creek site continued to grow and in 1928 the US Army Corp of Engineers developed a report and design proposal titled "Report on Cove Creek Dam Site and Recommendation for Design of Dam, Powerhouse, Barge-lift and Spillway." The design included a 220-ft tall barge-lift, that would be the first of its kind in the United States, and powerhouse at the center of the design and placed the spillway apart from the main structure to the east. The architecture of this original proposal included a series of archways for scale and ornament along the powerhouse and spillway. (*The Norris Project* 1940)

A series of the discussions and debates, many led by Senator George Norris, surrounding the dam projects continued into the early 1930's until shortly after the inauguration of President Roosevelt in 1933. President Roosevelt proposed legislation to form "a corporation clothed with power of government but possessed of the flexibility and initiative of a private enterprise," (*The Norris Project* 1940, 11) called the Tennessee Valley Authority (TVA). In May of 1933 the TVA Act was signed and the Cove Creek project, renamed the Norris Project in honor of Senator Norris, was authorized to begin construction. (*The Norris Project* 1940)

The Norris Project was simultaneously under both design and construction throughout its entire development, from the construction start in October 1933 to the opening of the dam in 1936. The team at the TVA, under the direction of Chairman, A.E. Morgan, began the project by hiring the Bureau of Reclamation to conduct engineering and drafting services for the dam. The Bureau of Reclamation conducted a feasibility study of the dam with four different structural types: a concrete straight gravity dam, a concrete round-head buttress, a rolled-earth fill, and a rock-filled. The study analyzed the required siting, layout and height of the dam as described through a series of preliminary drawings. Following the study, the Bureau recommended a concrete straight gravity-type dam (Fig. 1) as it would provide the lowest overall cost of construction.[1] (*The Norris Project* 1940)

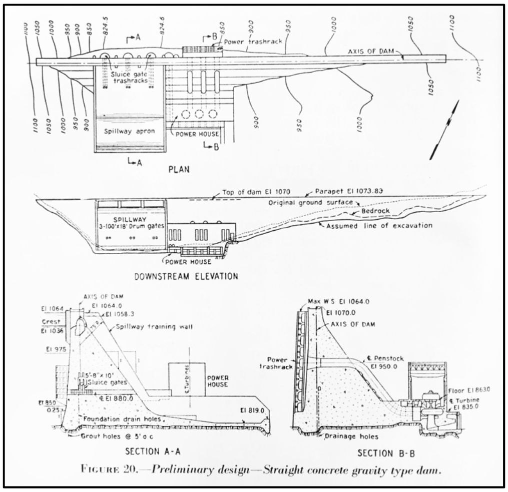

Figure 1: Bureau of Reclamation study of straight concrete gravity dam. (*The Norris Project* 1940, 48)

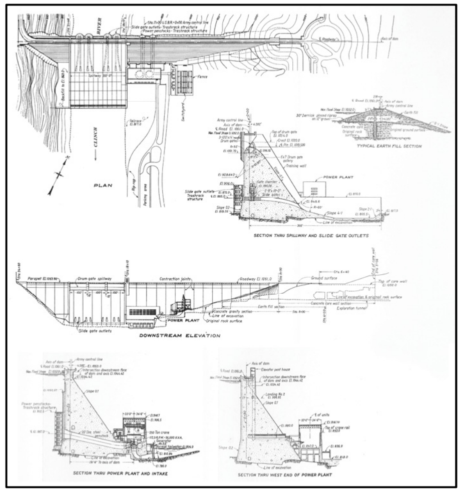

Figure 2: Norris Dam Plans, Elevations and Sections. (*A Technical Review of the Norris Project* 1937)

On the heels of the Bureau's study the TVA hired Roland A. Wank to become the Chief Architect for the dam under the Division of Land Planning and Housing. Wank is well known for pursuing a modern aesthetic in the design of Norris Dam, through the insistence on the removal of ornament and careful composition of the dam elements of the spillway, powerhouse, and roadway. Most noticeably, as can be seen by comparing the design by the Bureau of Reclamation (Fig. 1) to the final dam design (Fig. 2), the original design by the Bureau suggests exposed penstocks along the front face of the dam and vertical windows along the power house which differ from the final design with the penstocks hidden in the mass of the dam wall and the horizontal ribbon windows of the powerhouse.

2.0 HYDRAULIC MODELS

With the general massing and layout of the Norris Project defined, in 1934 the TVA with the Bureau of Reclamation designed and constructed an interactive hydraulic scale-model to test the engineering and architectural character of the dam design. The first photograph in Technical Memorandum 406 published by the Department of Interior Bureau of Reclamation in 1934 shows a completed model of Norris Dam scaled at 1:72 (Fig. 3). Evenly lit, shot frontally straight-on, the photograph shows a faithful replica of the project's overtop curved spillway, simplified plate-girder roadway bridging across the top, and the austere volume of the powerhouse. Decorative elements such as scale vehicles and window locations participate with the out-of-scale elements needed for the model's technical performance such as metal piping and a sandy river bed. Most notably the model in this photograph is very dry. There is a not so much as a drop of water visible in this photograph. While this model was at its time, a state-of-the-art technological device for testing the hydraulic performance of the dam, seeing it as an object to introduce this technical report is a reminder of the aesthetic seduction that miniature forms such as the architectural model is capable. (*Hydraulic Model Experiments* 1934)

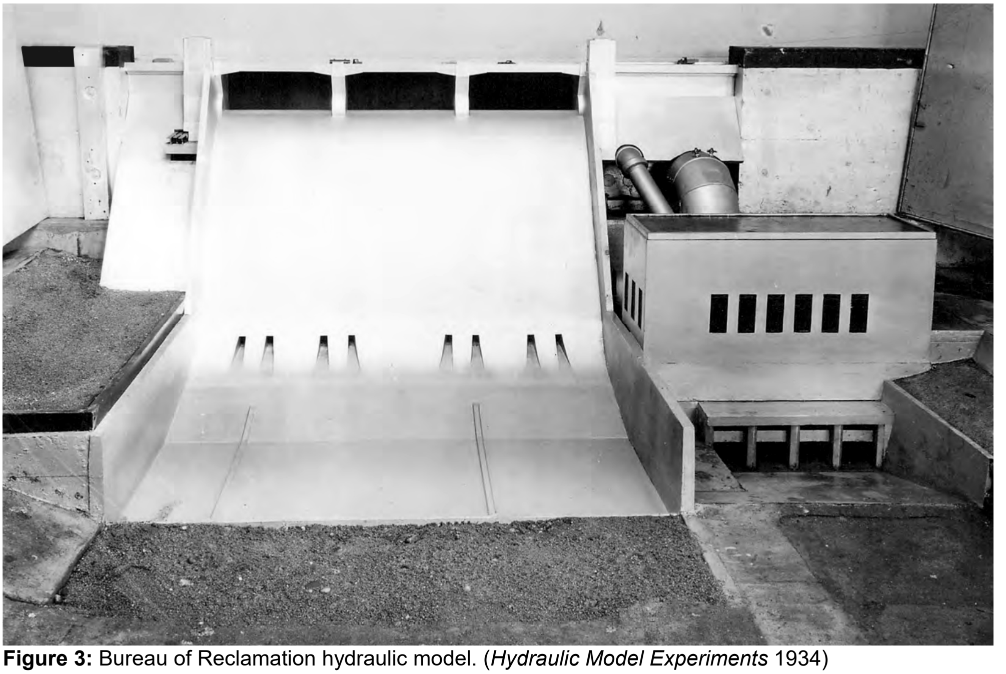

Figure 3: Bureau of Reclamation hydraulic model. (*Hydraulic Model Experiments* 1934)

Even with today's sophisticated computer models, the behavior of water flowing across a constantly changing river bed is notoriously difficult to predict. Furthermore, the effectiveness and feasibility of the solid concrete walls that the TVA sought to build to inhibit and control the rivers of the Tennessee Valley could not be guaranteed by scientific formulas alone (*Protection Against Scour* 1933). So, the Bureau of Reclamation design team utilized a physical model to test the form and appearance of the dam and to help predict the effects of water flowing through it. While this was not the first time a dam or engineering work had been studied through physical model, the process, documentation and artifact provide a compelling narrative of the potentials for the techniques of architecture representation to participate in the aesthetic production of engineering research.

The Bureau of Reclamation was formed in 1902 to administer irrigation projects in the arid regions of the Western United States, and their Colorado Agricultural Experiment Station in Fort Collins had only been building hydraulic models like this since 1930 (*Hydraulic Laboratory Techniques* 1980). The entire process of the Norris Dam model's construction, fluid and aesthetic testing and the resulting recommendations are painstakingly detailed in their Technical Memorandum No. 406, "Memorandum to the Chief Designing Engineer. Subject: The Hydraulic Model Experiments for the Design of Norris Dam" by Charles W. Thomas in 1934 which served as a primary source for this reflection.

The report uses drawings and photographs of the laboratory, model and dam to move the reader back and forth between the scales of both the TVA project of building a dam and the laboratory project of building a model. This oscillation between the work of representation and the built form is commonplace in architecture, and it is notable to see this similar balance of the importance of the final built work of engineering (the dam) with the attention paid to processes and procedures of the representation as carried out by the bureau. (*Hydraulic Model Experiments* 1934)

The space of the laboratory is first described through a series of four photographs that depict an idyllic rural setting and exterior structure that looks quite familiar like an archetypal pitched roof house. We then are presented with the supply reservoir—it's only hint at what might be happening inside. And finally, an interior photograph is revealed complete with the piping, ductwork and machinery that one would expect of scientific laboratory.

The laboratory building is then described in architectural plans and section with the model of Norris Dam located within "Calibration Tank X." As a planning document, we can see the complex arrangement of pipes and equipment that direct water to the study subjects. As an aesthetic artifact, we also are given a full picture of the project of the model and the laboratory within which it is housed. With the knowledge that water flows downhill, the building cascades down a hillside with the holding reservoir above the weir box which can then be diverted into either of the small testing channels or the large Calibration Tank X, with the floor dropping another full story. Another TVA project, the Wheeler Dam is noted on the drawings in the one smaller testing channels. All of this complexity however is neatly captured with an even pitched roof, and regularly spaced double hung windows. The celebration of this technical ingenuity is left for the pages of government memorandums, and not aesthetic conceits of architectural form.

The report then briefly describes the plans and site for the final design of the dam before changing scale again to the drawings and details of the 1:72 scale model. The same format of construction drawings and documentary photography depict the model as both a performative device as well as an aesthetic creation. The model was constructed of steel, wood and masonite, and as noted in the report, "the entire model was carefully finished and painted with extra bright aluminum paint" (*Hydraulic Model Experiments* 1934, 12). Reading the drawings provided, one finds that while architectural features are kept to scale, the "plumbing" around and through structure is carried out with conventional pipes and fittings. This is because of the siting of the model within the Calibration Tank creates a necessarily different relationship between the dam and the reservoir then would occur in the hills of Tennessee. Also, the velocity, volume, and pressure of water does not have such a tidy scalar relationship to the model as the scaling of architectural forms would have

Regardless, with a single model, the designers were able to study many things that the report divides into three categories: Spillway Studies, Auxiliary Passages and Architectural Studies. While the Architectural Studies are given notedly less ink than the other two categories, that they are included at all in such a technical study reads like a victory for design and aesthetics. Before looking at the results of these studies, it is important to note that as with the documentation of the Laboratory building, the drawings and photographs describing the model amount to a form a knowledge sharing that place importance on the production of a technical and architectural model as not only applicable for Norris Dam, but they were meant to serve also as a "model" for future dams and their designers.

The Spillway and Auxiliary Passage studies form the majority of this report as they study the shape of the spillway apron, stilling pools, and the openings through which the water exits the dam. (Fig. 4) Like in any building, joints and openings are a critical concern for the designers of dams. Not only must the joints within a massive concrete wall be carefully engineered, additionally the joints in which the man-made structure meets its earthen context are important moments in which the apparent heaviness of construction must respond to intricate conditions. The wall of the dam meeting the wall of the canyon in the vertical plane is one of these moments. Of equal importance is the way in which the horizontal surface of spillway's stilling pool transitions into the natural rocks and mud of the riverbed on which it is constructed. This must be designed to dissipate energy in the water and alleviate the potential for scouring of the river bed adjacent to the concrete spillway.

Scouring is the hydraulic phenomenon in which the water flowing around an impediment or barrier has the tendency to erode the riverbed on the downstream side of that barrier and hence compromise the ground in which that barrier relies on for support. (*Protection Against Scour* 1933) One can imagine the catastrophic effects on a dam if the ground below it begins to disappear downriver. Despite formulas and proofs utilized to optimize the shape of the spillway in the design phase, physical testing is still necessary to confirm these assumptions.

And the lab technicians document countless iterations of these tests examining different shapes, transitions, water quantities, and patterns of operation. All the while, the technicians pay careful attention to the character of the water flowing over the surfaces and leaving the controlled conditions of the stilling chamber.

Only once a degree of confidence can be imparted on the hydraulic engineering of the structure, does the report discuss the Architectural Studies, and it does so in slightly less detail than hydraulic tests. While only the roadway bridge over the spillway was studied architecturally, it is still treated with the same seriousness as the engineering concerns. The same documentary language and photographic process was used to try to establish a verifiable conclusion for aesthetic decision-making by means of comparison. (*Hydraulic Model Experiments* 1934)

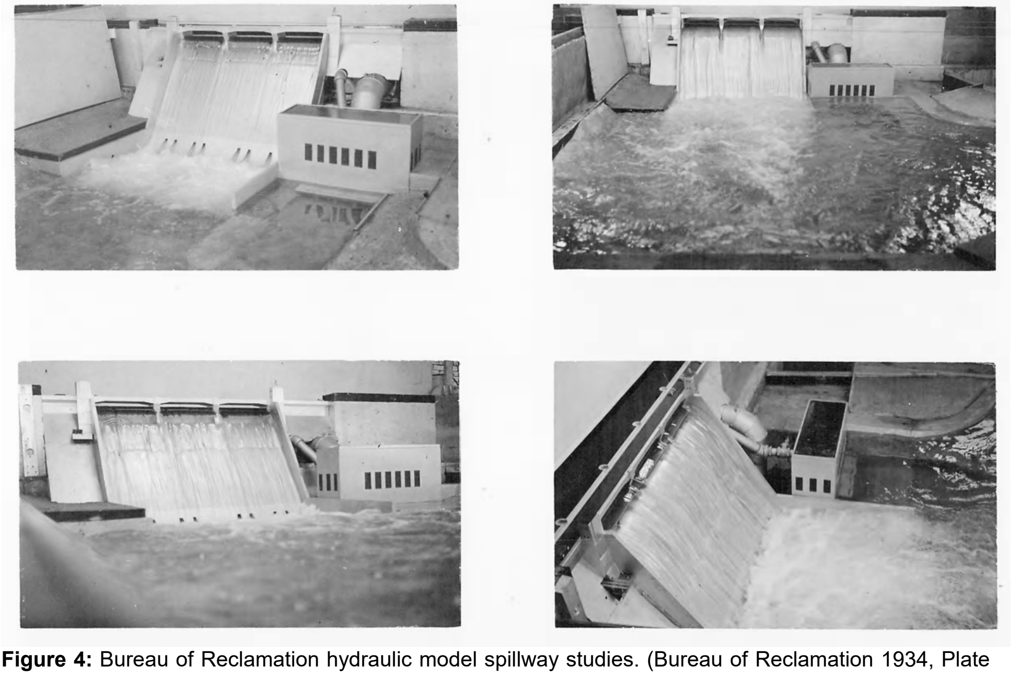

Figure 4: Bureau of Reclamation hydraulic model spillway studies. (Bureau of Reclamation 1934, Plate 68)

The roadway bridge had three structural options to be studied for aesthetic impacts: A through truss, a pony truss, and plate-girders. The through truss and pony truss were both steel framed options with exposed steel members that were deemed to be out of proportion with the rest of the concrete dam. However, using steel pates in the plate-girder system gives the appearance of a monolithic roadway, that is “much more in keeping with the other features of the dam and adds greatly to the appearance of the structure.” (*Hydraulic Model Experiments* 1934, 183) Beyond aesthetics, the engineers note that changing the pier structures to accommodate this is actually beneficial to the flow of water over the bridge.

It’s difficult to determine when in the process of Hydraulic Testing that the Architectural tests were performed. Sometimes the photos of the model show the plate-girder bridge, sometimes they show no bridge, and sometimes the through truss is visible. The bridge piers are drawn in the construction drawings of the model but not the roadway. This indicates that the architectural studies were intended from the beginning, and the model was constructed to be modified both technically and aesthetically. Decorating the roadway with scale models of cars and trucks as in the final model shots, the bridge is able to effortlessly find its way into the testing, and its presentation in the report show a receptiveness of engineering practices toward the production of an aesthetic project.

3.0 THE STRUCTURAL MODEL SHOP OF THE TVA

The concurrent design and construction of the Norris Project raised many challenges that required real-time study of the architecture, hydraulic design, structure, and constructability. To aid in many of these complex studies the TVA built Structural Model Shop at the Norris site with trained engineers and model-makers to make scale-models and mock-ups of various project elements at Norris, as well as other ongoing TVA projects. In a 1938 pamphlet of the TVA Structural Model Shop, director H. L. von Hohenleiten describes the breadth and usefulness of the Model Shop’s services, suggesting that other departments with the United States government may also want to employ the shop’s skills. The pamphlet categorizes the work of the model shop into 5 model categories: architectural models, topographic models, construction models, electrical models and special models. At the front of the pamphlet Hohenleiten describes the engineering discipline’s recent adaption of this “new medium” and its ability to provide an effective way to study complex three-dimensional design problems. Hohenleiten continues to emphasize the practical benefits of using scale-models in the design process stating: “In many instances models have more than repaid their cost by providing a miniature picture that could bring a story home to the laymen where intricate blueprints had failed.” (The Structural Model Shop 1938, 1)

The five types of models that the shop produces are notable in that they were intended to study different aspects of the dams in detail. The architectural and topographic models were typically constructed at the smallest scale and encompassed the entire structure of the dam and proposed buildings. These models, as they are commonly used today, allowed the TVA Architects to “visualize all his problems before design drawings are completed.” (The Structural Model Shop 1938, 2) The pamphlet also notes that the architectural scale models are often produced with inter-changeable parts to test different design options. The topographic models in particular allowed the TVA team to understand the three-dimensionality of the dam interventions in connection with the surrounding landscape.

A finer level of detail is found in the second category called construction models. These models were used to understand the constructability of the projects, as well as the sequence of construction. The models were designed to be taken apart and reassembled to give the contractor a better understanding of the construction sequence. Some of the models were in addition designed to be taken apart in section, to produce a three-dimensional cross-section of the project. The models are made with a high-level of craft and precision allowing for them to both describe the constructability but also to highlight the architectural details of the deign down to the concrete scoring patterns.

The last two model categories described in the pamphlet, electrical and ‘special’ models, undertake some of the more progressive and experimental aspects of the TVA designs. Lighting of the Norris Project became particularly important to Roland A. Wank, as he wanted the lighting to become part of the scenery and enhance the approach and appearance of the dam design. In a series of letters between Roland Wank and the Norris Dam the Office of the General Manager in 1938, two years after Norris Dam had opened to the public, Wank requested the addition and of flood lights illuminating the face of the dam, as well as addition of light fixtures in the parking lot. Wank desired an even illumination of the visitor parking lot and the dam itself as not to blind the visitors on approach. (Roland A. Wank 1938) As part of the lighting study, the architect’s office designed a baffling system for the parking lot lights that would help distribute the light evenly. The design was tested in a series of models and installed as a full-scale mock-up on site. At this point the Structural Model Shop was acting as much as a fabrication service, producing full-scale pieces that could test the designs prior to full production. The pamphlet notes:

> A lot of the research work is being done in connection with these models in order to establish not only the correct optical features, but also to determine the proper chemical and mechanical properties of paints and materials.” (The Structural Model Shop 1938, 6)

The electrical models suggest a true collaboration between the architects and the engineers as the aesthetic effects of the architect's office are refined and tested through the physical mock-ups.

The special models section of the pamphlet describes the Structural Model Shops ability to test a wide-range of design and visualization challenges through physical models. The two examples described in the pamphlet are both quite interesting and operate at different scales. The first special model described is a skeletal model of a draft-tube, a mechanical element that sits below the power house. The draft-tube was built with a series of sectional flat sectional members that form a lattice or skeleton of the entire geometry. (Fig. 5) The model appears strikingly similar to digital lattice models generated by the computer to that architects commonly use to model complex surfaces still to this day. The pamphlet notes the difficulty of the team to visualize this complex geometry through drawing alone.

The other unique model to note in this section is a scale model of the crusher plant. (Fig. 6) The extremely large quantity of concrete utilized in the Norris project led the TVA to construct a local concrete plant for the Norris Project. Rock was quarried from the surrounding hills of the dam and transported to the concrete plant to be processed. In the design of the concrete plant, the model shop built this scale model that included the "mechanical elements like screens, chutes, and crushers" that could be easily reconfigured in the model "until an economical and mechanically correct layout could be developed." (The Structural Model Shop 1938, 11) The reconfigurability of the model gives it a children's game-like quality with a series of primitive parts set with a light structural frame.

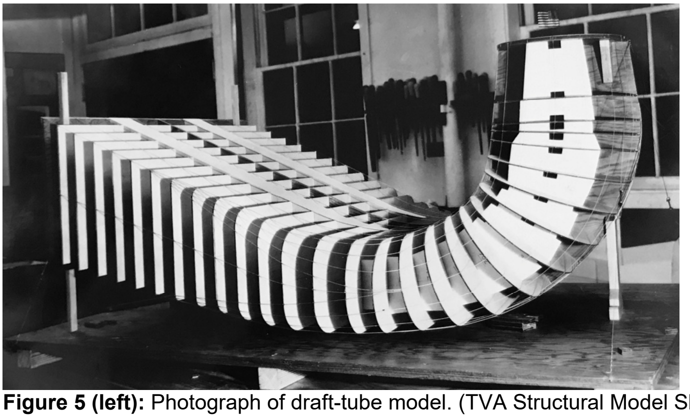

Figure 5 (left): Photograph of draft-tube model. (TVA Structural Model Shop pamphlet 1938)
Figure 6 (right): Photograph of crusher plant model. (TVA Structural Model Shop pamphlet 1938)

The extensive amount and variety of models constructed in the TVA Structural Model Shop are impressive and suggest a detailed level of study into all of the building components, but it also demonstrates an interesting space of collaboration between the architects and engineers. The model shop, where neither the Bureau of Reclamation or the Architect's office was necessarily physically present, was a moment where the ideas and strategies of both groups were brought together and tested in a controlled environment. The detail and precision of the models and mock-ups constructed suggest that they were used for both purposes throughout the design, aesthetic sensibility and refinement of performance.

CONCLUSION

After the dam's completion, heavy rains in January of 1937 provided an opportunity for the TVA to test the performance of the constructed spillway against the results predicted by the Bureau of Reclamation's laboratory tests (*Performance of Norris Stilling Basin* 1938). A remarkably similar set of photographs to the hydraulic model photos of water flowing over the dam on an overcast day are produced looking closely at the characteristics of the water flow.

The photos are distinguishable from the laboratory photos only by the apparent scale of the water compared with the scale of the structure. The concrete of the dam also takes on more detail and patina than the physical model could ever depict. The design process from drawing, to model, to construction is complete, but the memory of the model and the artifacts of the process are engrained in the artifact and its operators.

As the need for the design of new infrastructure meets the demands of maintenance, resiliency and decommissioning of aging infrastructure, architects have new opportunities to inject aesthetic possibilities for design work that will otherwise be relegated to engineers, industrialists and politicians. The signature parks, iconic bridges, and academic speculation are a good start for maintaining a thread of the discipline of architecture's attention toward infrastructure. However, there is much work to be done to inject design into the gaps in mindfulness that are ubiquitous in the extensive reaches of global infrastructure.

The models that are covered in this paper represent a collaborative and interdisciplinary tool to test both aesthetic and performative potentials of an enormous project. The model shops at work here established a neutral ground outside of the hands of the projects designers to give life to their ideas and drawings. The model's physical presence, transmitted through photographs, made it seem possible to have an objective vision towards and aesthetic production.

Today's professionals also operate in a digital modeling environment heralded for its potentials for seamless real-time collaboration. What needs to be questioned is the capacity for that type of model to promote new aesthetic possibilities that are capable of transcending the ambitions of any single stakeholder in the project. While the architects of the TVA had the momentum of the Modern Architecture movement to propel their aesthetic agenda for the Norris Dam, architects today, for better or worse, enjoy a much wider field of aesthetic possibilities from which to bring to the collaborative table. The model making practices of the TVA give promise to the notion that aesthetic imagination must complement the engineering of infrastructure if we are to thoughtfully address the infrastructural needs of today.

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ENDNOTES

1 Scholars, including Reyner Banham and Christine Macy, have suggested that Roland A. Wank and the TVA Architects critiqued and re-designed the Norris Dam design based off of the preliminary design proposed by the United States Army Corp of Engineers in 1929. However, the four preliminary dam studies developed by the Bureau of Reclamation in September 1933 from the Norris Project Technical Report suggest that the concrete gravity dam design was selected for its cost benefits prior to Roland A. Wank's arrival to the TVA in October 1933. This timeline would suggest that the general composition of Norris Dam was already in place when Wank's team began work at the TVA, shifting the common narrative of the dam's design inception. This historical timeline merits further study.