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Robotic tile placement: Tools, techniques and feasibility

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ABSTRACT

The project develops an integrated digital workflow [1] for robotic tile placement that allows off-site use of industrial robotics for on-site tiled surfaces, and tests feasibility in the context of the tile industry. The proposed approach overcomes limitations of existing methods that focus on efficiency [2,3] by enabling unique and complex tile patterns. A design experiment is used during the development of computational and robotic technologies. Integration and industry implementation were studied through interviews with experts, field studies, and literature research that included a review of U.S. tile installation standards [4]. A *Rhinoceros™* based digital workflow was developed that includes complex pattern generation, integrated robotic programming and simulation, and cost/time estimation. The paper describes strategies for pre-tiled panels, recommends specific material combinations, and includes basic cost estimation in the context of construction. Robotic tile placement ultimately adds value by moving installation of tile patterns to the place of tile production.

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1. Introduction

The steady increase in the price to productivity ratio of industrial robots over the past decades is opening up new application areas that include the production of architectural ceramics. Research at Harvard University's Design Robotics Group (DRG) has been studying specific opportunities for integrating robotic technology with an initial focus on product customization and related workflow [1]. The research presented in this paper summarizes a feasibility study of robotic tile placement, an area that has received little attention in recent years. The research developed a computational environment that facilitates the generation of image or pattern-based tile designs and an integrated design-to-robotic-fabrication tile placement workflow. Both are based on the low-cost and widely available digital design software platform *Rhinoceros™* (*Rhino*).

The integration of robotic tile placement into the construction industry requires a re-design of current placement strategies [2,3]. The envisioned system can be considered a true mass-customization approach whereby the cost of the customized product is similar to that of the standard product. The added value of complex tile pattern designs does not come at a cost premium.

Once tiles have arrived at the point of installation, the state-of-the-art, computer-controlled, high-volume tile production-to-distribution process rapidly downgrades into a purely analog handling of the material. Tile installation remains a manual process supported by simple tools that have remained unchanged for decades. Tile installers and tile producers have few common points of contact and take little mutual interest in their related, yet sharply separate, domains. Innovation in production has not transferred to installation with its many small geographically and economically fragmented participants. Issues of tile installation warrant a new study in the context of advances in robotic technology.

In developed economies with high labor rates tile installation costs remain a major factor in the overall cost of tiled surfaces. For example, in Boston, MA, unionized tile installer labor costs for laying mosaic tile on 1 ft^2 netting is 30–35 $/$ft^2$ and non-union labor is 15–20 $/$ft^2$. An increasingly felt shortage of qualified construction workers especially in the United States has aggravated already existing issues of installation quality. The range of feasible tile patterns is extremely limited and highly repetitive, poorly reflecting the sophisticated production technology underlying contemporary tile production.

To address these current problems of tile installation, and in an attempt to bridge the gap between producers and installers, the research investigates the use of robotic technology for tile installation as a way to address cost, time, and quality, both in terms of accuracy and design.

Existing approaches to robotic tile placement are reviewed first, followed by a report of the research conducted by Harvard's DRG. The study concludes with a discussion of issues regarding implementation and construction integration, as well as an overview of next steps needed for industry integration.

2. Tile installation: State of the art

Currently the production of complex tile patterns exists in the form of pre-assembled mosaic tile sheets, a largely automated process. While individual sheets contain complex arrangements they are used in aggregate to form repetitive patterns without the possibility of customization. The majority of custom ceramic tile mosaics are assembled by hand but several precedents do exist for the robotic placement of custom tiled mosaics. *Artaic*, for example, a Boston based producer of

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custom mosaics, uses a single robotic work-cell to fabricate custom mosaics. During the *Artaic* process a digital image is discretized into tile pixels using proprietary color matching software and then divided into standardized 1 ft^2 sheets. Each tile pixel is robotically placed into a registration grid and an adhesive sheet is applied to support the pre-assembled mosaics during shipping and installation where they are installed and grouted by hand [5].

A similar, yet fundamentally different, variation is used by *Top Hat Tile*, which achieves image-based customization of tile mosaics through individually glazed tile pixels. In this example a 1 ft^2 assembly of small, unglazed tiles is loaded into a custom robotic work cell that applies or prints a custom solid-colored glaze on each individual tile. Again, the robotically assembled mosaics are installed in 1 ft^2 sheets by hand [6].

Images and patterns can also be directly digitally printed onto often large-format tiles. This technology, while increasingly popular, is outside of the scope of this study which relies on tonal difference of grout and tile to produce legible images.

3. Concept and workflow development

Today tile installation is done almost exclusively by hand. During this study opportunities for robotic installation were explored through two prototypical scenarios that addressed the process from computational design to physical implementation. Using integrated computational design, two modular workflows were used to generate the arrangement of tiles, as well as the machine code used to drive the robotic placement. The first workflow uses a randomized pattern of standard tiles with varied dimensional format. The second uses dimensionally modular tiles to recreate a digital image within the contrasting grout lines.

3.1. Computational tile patterning

The digital workflow for creating robotically placed ceramic tile panels consists of four components. Two are used to generate parametric tile arrangements, and two are used in the robot code generation, simulation and validation. For this research all of the modules were in the form of custom components written in C# for *Grasshopper™*, the visual programming interface for *Rhinoceros*.

3.2. Pattern based digital workflow

A series of algorithms were developed to enable packing tiles of various formats into orthogonal patterns characterized by various degrees of regularity and randomness (Fig. 1). Packing areas, defined by curves, and the resolution of the grid on which the pattern is based are the primary parameters of the system. Variables control the degree of randomness in the pattern and the number of tiles of each format. The pattern can accommodate any tile size, however, when using standard tile formats whose dimensions are not necessarily perfect multiples of each other, the script allows for irregular tile spacing in order to accommodate the discrepancies. Possible applications of this system include situations where there is a desire to create patterns possessing a degree of irregularity while using standard format tiles.

3.3. Image based digital workflow

The image-based strategy uses the density of the grout lines in order to express the tone variations of the input image. As a proof of concept an iconic portrait of Marilyn Monroe was chosen to demonstrate the ability of the script to recreate something as complex, and uniquely identifiable, as the human face.

Expanding upon the pattern-based system the image-based workflow focused on maintaining equal spacing between tiles thus requiring the use of a modular tile system dimensioned on a grid. A grayscale image is used in order to drive an adaptive subdivision scheme which results in smaller tiles clustered near either darker areas or sharper edges. A grayscale translation (Fig. 2) creates the most photorealistic result by converting lighter areas to larger tiles with fewer grout lines. In addition, it is possible to give the impression that tiles are following the contours in the image by increasing the grout areas and rotating the tiles so that they align with the image gradient.

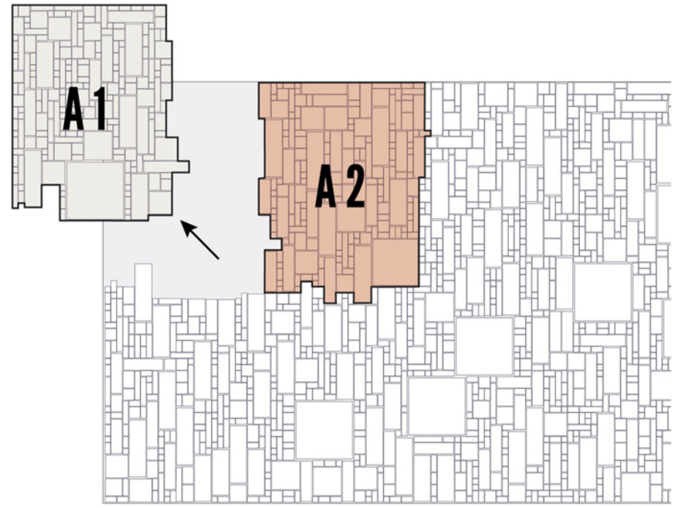

Fig. 1. Generated pattern using weighted randomness.

3.4. Integrated programming of robotic placement

The third module in the workflow converts any set of *Rhino* surfaces, representing tiles, into a series of movement commands for the ABB robotic arm. In Fig. 3 the lines indicate this robotic movement sequence from a source point, to an intermediary point above the source, across the table to an intermediary point above the destination, and finally directly down into the destination. Intermediary points are necessary in the movement to avoid collision and to ensure the motion of the final placement is perpendicular to the placement surface.

The module takes as input any number of 'destination' and 'source' tile positions modeled as *Rhino* surfaces. The module can accommodate stacked source tiles by inputting the number and thickness of tiles at each source position. The script then automatically identifies and matches every destination tile to its corresponding source tile stack. The program keeps track of the number of tiles in each stack and adjusts the elevation of the suction gripper accordingly. Multiple stacks can also be defined. In this case the module will direct the robot to source each tile from the stack of the right type until the stack is empty, at which point an alternate stack is chosen. If no stack information is provided the script assumes the source location is 'infinite', meaning that tiles are replenished every time one is removed. The robot will continue to revisit the same source location until the process is complete. Additional work object or backer board dimensions serve as input parameters that will universally translate all of the destination tiles vertically.

The module then outputs a text file written in RAPID code, the instruction language of ABB robots. This file can be loaded directly into the robot to begin the process. It is typically necessary to simulate robotic movements in the proprietary ABB software RobotStudio. In order to bypass this step and make the workflow seamless an inverse kinematic solver, previously developed by Harvard Graduate School of Design faculty Prof. Panagiotis Michalatos, was used to visualize the robotic movements. This fourth module is independent and the robotic code can be generated separately if desired. However, the visualization of the robot movements within the *Rhino* environment greatly reduces the likelihood of error. Each file was simulated in both RobotStudio and the inverse kinematic solver to validate the tool.

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