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TITLE: Development of the Wheelchair In-Seat Activity Tracker (WiSAT)

PRINCIPAL INVESTIGATOR: Stephen Sprigle

CONTRACTING ORGANIZATION: GEORGIA TECH RESEARCH CORPORATION, Atlanta, GA 30332

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14. ABSTRACT
Pressure ulcers remain a critical problem for persons with spinal cord injury (SCI), with negative consequences on nearly every aspect of their lives. Research and clinical experience suggests that weight shifts are an important part of promoting tissue health. This project seeks to design a commercially-viable system to inform wheelchair users about their weight-shifting activity as a means to promote healthy behaviors and prevent pressure ulcers. Termed the WiSAT (Wheelchair In-seat Activity Tracker), it will have impact on wheelchair users, their clinicians and researchers. Such a product can empower wheelchair users with knowledge about their behaviors associated with pressure ulcer prevention

15. SUBJECT TERMS: pressure ulcer; wheelchair; weight shift; spinal cord injury; behavioral change; interactive technology

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1. INTRODUCTION:

Pressure ulcers remain a critical problem for persons with spinal cord injury (SCI), with negative consequences on nearly every aspect of their lives. Research and clinical experience suggests that weight shifts are an important part of promoting tissue health. This project seeks to design a commercially-viable system to inform wheelchair users about their weight-shifting activity as a means to promote healthy behaviors and prevent pressure ulcers. Termed the WiSAT (Wheelchair In-seat Activity Tracker), it will have impact on wheelchair users, their clinicians and researchers. Such a product can empower wheelchair users with knowledge about their behaviors associated with pressure ulcer prevention

2. KEYWORDS:

pressure ulcer; wheelchair; weight shift; spinal cord injury; behavioral change; interactive technology

3. ACCOMPLISHMENTS:

- **What were the major goals of the project?**

	Timeline
Task 1. Develop WiSAT hardware and mobile app	1-12
Task 2: Develop classification algorithms	1-6
Task 3 Engage wheelchair users in usability studies	13-20
Task 4: Pre-Clinical Trial to assess acceptability, usability and impact of WiSAT	19-36

- **What was accomplished under these goals?**

Task 1. Develop WiSAT hardware and mobile app

WiSAT System can be described as having three goals:

1. Measure In-Seat Activity
2. Process and classify data into in-seat activity metrics
3. Provide users with reporting of in-seat activity

To achieve these goals WiSAT has 3 functional subsystems: a hardware module, classification algorithms, and a mobile phone application. Status of each subsystem will be presented in this section.

Hardware module design:

A specification table is maintained to report the hardware and firmware. The current table is contained in Appendix 1. A brief reporting of key design iterations is listed here.

Case and connectors. The data modules from Gulf Coast Data Concepts are in the final stages of choosing an appropriate connector that is both robust and reliable. GT is in discussion with GCDC on incorporating these connectors in their modules.

Data Storage and communication. JSON data will be stored in flat files and accessed via USB or through the Bluetooth API. We defined an API to allow the mobile application to communicate with the data module via Bluetooth 4.0 Low-Energy. The API allows data to be sent batched or as a continuous stream upon request. Data will be serialized as JSON objects and will include sensor data, hardware system status, and battery life information.

Inductive Charging. IDT's inductive charger was chosen (P/N: P9235A-R v2.1/P9027LP-R-EVK) and tested for compatibility to charge through various cushion cover material as well as locations relative to the zipper. The inductive coil was placed directly over the zipper and allowed to charge for a minimum of 5 hours and the heat from charging was localized and just over normal body temperature reducing the risk of injury from overheating. Work has been started on a housing for the inductive charger that would insure appropriate contact as well as a way to make sure the charge is not placed on incorrectly.

Seat sensor. Mat design is being finalized for Tekscan that will allow for adjustments to the width to insure proper placement and fit with users' cushions. Print design is being finalized to allow for more than one mat to be printed per screen reducing production cost. Connectors are being finalized on the mat end to allow for connection to the pig tail connector or module.

Mobile Phone app

Extensive effort was spent in designing the mobile phone app and hiring a subcontractor to develop the Android and IOS versions. The data flow diagram for the mobile phone app is listed in Appendix 2. This diagram served as the primary introduction during solicitation of bids from developer. As noted, design of the mobile app requires certain hardware and infrastructure design, most notably the API (application programming interface) for the WiSAT module and the remote server.

The bid process was governed by Georgia Tech and include solicitation and review of bids in advance of awarding a contract. Apeiro Technologies, with offices in Atlanta and elsewhere, was awarded the contract which commenced on July 1, 2018

The other activity concerned design of the User Interface, including screen designs for the major functions of the app. Initial renderings are depicted in Appendix 3. These are currently undergoing revision in advance of a usability study into their design

Task 2: Develop classification algorithms

The goal of developing the classification algorithm includes multiple steps and smaller goals. These goals, as defined in the proposal, were:

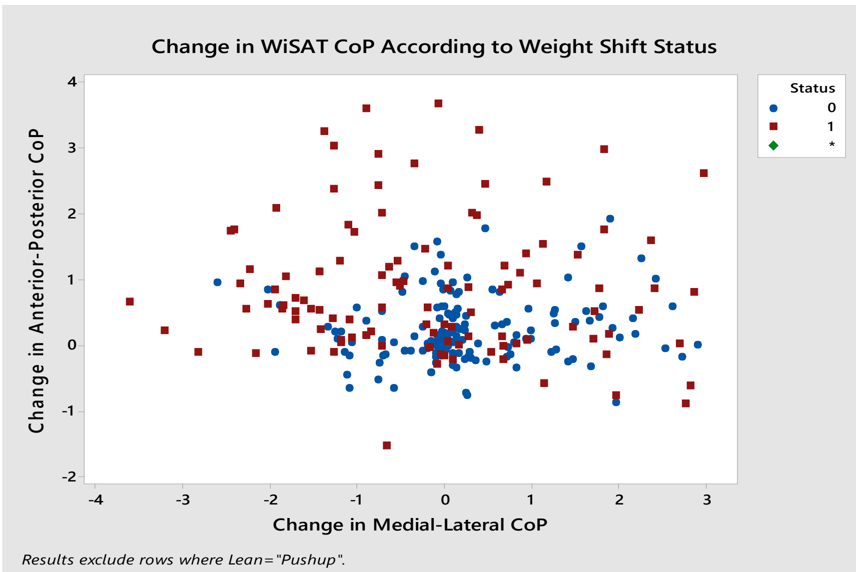
1. Refine algorithm to classify weight shift and pressure relief behaviors in real-time.
2. Develop initialization procedures.
3. Determine algorithm accuracy.

Refine Algorithm

Refining the algorithm to perform in near real-time required us to develop a new baseline calculation with lower computational cost – this was completed successfully. We also developed two support vector machine classifiers for detecting wheelchair occupancy. The first was intended for real-time use and does not use floating point numbers. It is biased to almost never mistakenly classify data as out of chair. The goal is to have a classifier that can be implemented directly on the hardware to determine whether or not data should be transmitted via Bluetooth to the app, thereby reducing battery consumption. A secondary occupancy classifier intended to be implemented on the mobile app with greater accuracy was also trained.

Refining the algorithm that classifies weight shifts has been a longer process. We have largely driven that process with existing data collected in previous studies. However, a robust classification algorithm requires truth data collected on the latest seat sensor and hardware. To date, 9 subjects were studied on 3 pre-determined wheelchair cushions performing a controlled series of leans and weight shifts alternating with upright sitting. We expect to collect data on more subjects in the coming months.

We have focused our efforts on identifying the optimal features to use for analysis, selecting the type of classifier to use, and identifying what information is important for initialization (discussed below). Change in center of pressure and normalized total load were identified as relevant features.



The graph above illustrates the change in center of pressure within our data set. Each data point illustrates change in center of pressure along two axes in the plane of the seat on our WiSAT, and is colored by whether or not a weight shift occurred. As you can see, points at the periphery are easier to identify as a weight shift, while point near the center are most likely to not be a weight shift. In between, however, the status of the points requires more information to determine.

Different classification approaches have been considered during this process, including support vector machines (SVM), hidden markov models, nearest neighbor, change point detection, and neural networks. Hidden markov models, nearest neighbor and change point detection have been ruled out at this time – while each provide some value, the complexity and/or increased processing times they add are too great at this time. We trained an SVM classifier based on the previously mentioned features across all predicate training data and achieved an accuracy of 90% on a holdout of set the training data. Our current efforts including training a similar classifier on the newest data collected on the latest hardware and optimizing a tuning process using initialization data as described below. In parallel to developing the SVM classifier, we are continuing work with Road Narrows on a neural network approach to determine if it can produce improved classifiers compared with the SVM approach.

As Bluetooth hardware became available, we also had the opportunity to begin implementing and testing in realtime. We built our first real time classifier than could be run on a laptop and observed in real time during human subject data collection. We are also in the process of implementing the occupancy detection algorithm for the mobile app.

Initialization Procedures

In our research work studying in-seat movement, we individually trained a classifier for every research participant. This provided great accuracy at using sensors to predict in-seat movement, but at the cost of a very involved set-up procedure that is not possible for a commercial product. However, variability across users, including their wheelchair configuration, wheelchair cushion, body type, etc., all contribute to differences in the forces read by the sensors that impact the classifier. Therefore, we have been trying to identify differences across conditions that can be considered in the algorithm through an initialization process without requiring a complete training session.

Our review of the data showed that errors were not biased to a particular cushion or individual characteristic. Variability across users with the same wheelchair cushion proved so high that initialization based on cushion type does not seem to be the answer. Instead, initialization is likely to key off of asking users to perform a few movements, and data from those movements would be used to scale the overall classifier. We are currently testing this approach, and initial results are promising.

Algorithm Accuracy

Validation of the classifiers was initially completed on predicate data collected on older hardware, but data collection for validation on the current hardware has begun. So far, we have collected data on 5 individuals each seated on a single cushion to collect a 90 minute controlled validation dataset. We expect to collect an additional 5 subjects in this controlled manner, and then collect individuals performing a set of functional activities rather than controlled leans as a secondary validation set. Validation results are not yet available.

- **What opportunities for training and professional development has the project provided?**

  Not applicable

- **How were the results disseminated to communities of interest?**

  Because we have been measuring weight shift behaviors for several years, we are able to report findings and from the current project in combination with results from prior work. Conference presentations, attended primarily by clinicians and researchers, have included aspects of the current project.

- **What do you plan to do during the next reporting period to accomplish the goals?**

  We have inferred that "next reporting period' means the next 3 months since a Quarterly report will be due

  Task 1. Develop WiSAT hardware and mobile app
  - Seat sensor: final design will be completed and sent to Tekscan for fabrication
  - Module: the V3 module design will be fixed, allowing Gulf Coast to begin fabrication of the units needed for the pre-clinical trial

- Mobile App: since the software vendor has been hired, and their timeframe defined, we can anticipate that the initial functional prototype will be deployed for testing; final app development will be achieved in Fall 2018.

Task 2: Develop classification algorithms:

- Completion of the 'occupancy' algorithm and packaging it into a coded library

Task 3 Engage wheelchair users in usability studies

- Submit IRB for usability testing of the interface
- Complete usability testing
- Finalize UI screens

4. **IMPACT:**

- **What was the impact on the development of the principal discipline(s) of the project?**

  This project represents translation of prior research into technology development. As a result, the technology development activities will extend clinical capabilities and will represent new technology innovation. Because the activities in Year 1 are formative, impact on disciplines was not a goal.

- **What was the impact on other disciplines?**

  Nothing to Report

- **What was the impact on technology transfer?**

  The objective of the project is to develop a commercial product, the WiSAT. Consistent with that objective, all development activities within the reporting period were designed to advance technology development and to position it for licensing.

  Project staff continue to disclose the availability of the WiSAT to potential licensing partners. This has been done via word-of-mouth. In addition, Georgia Tech's Office of Technology Licensing lists the WiSAT as available technology.

- **What was the impact on society beyond science and technology?**
  - Nothing to Report

5. **CHANGES/PROBLEMS:**

- **Changes in approach and reasons for change**
  - Nothing to report
- **Actual or anticipated problems or delays and actions or plans to resolve them**
  - Within Year 1, we have incurred a delay in developing the classification algorithms. We do not view this as a significant delay, but we are not on the pre-defined schedule. As detailed above, we have made steady progress. Suffice it to say, this is a non-trivial challenge so requires design iteration. Since the classification algorithms must be incorporated into the mobile phone app, we must define them by Q2 of Year 2, and are on schedule for that deadline

- A delay in contracting with the application developer resulted in development being delayed into Yr2. The process of Georgia Tech was lengthy and not very efficient. It required months. However, the contract is signed and development is underway

- **Changes that had a significant impact on expenditures**
  - The primary impact on expenditures resulted from the natural inertia of initiating a project and establishing staffing, and initiating work. We do not deem this as having a significant impact but w Describe changes during the reporting period that may have had a significant impact on expenditures, for example, delays in hiring staff or favorable developments that enable meeting objectives at less cost than anticipated.

  - **Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents** Nothing to report

- **Significant changes in use or care of human subjects:** none

- **Significant changes in use or care of vertebrate animals.:** N/A

- **Significant changes in use of biohazards and/or select agents:** N/A

6. **PRODUCTS:**

- **Publications, conference papers, and presentations**: none

  - **Journal publications.** *none*

  - **Books or other non-periodical, one-time publications.** None
  - **Other publications, conference papers, and presentations.** This project, in additional to prior work from the principals, embodies the area of in-seat movement of wheelchair users as a means to promote tissue health. As a result, conference presentations include information from both the current study and prior studies. It is not trivial to separate them. Presentations within the last reporting period include:

International Seating Symposium: Vancouver, February 2018
AAWC Pressure Ulcer Prevention Summit; Atlanta GA, February 2018
European Seating Symposium, Dublin, May 2018

- **Website(s) or other Internet site(s);** None

- **Technologies or techniques:** None

- **Inventions, patent applications, and/or licenses**
  US Utility patent application: Wheelchair in-seat activity tracker
  August 9, 2017

  - **Other Products:** none

7. **PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS**

- **What individuals have worked on the project?**

Name	**Stephen Sprigle**
Project role	**PI**
Research ID (ORCID)	0000-0003-0462-0138
Annual Person-month effort	**2.0**
Contribution to project	**Overall project management include liaison between DoD, Georgia Tech and clinical sites; design duties include project management and design team coordination.**

Name	*Sharon Sonenblum*
Project role	**Senior Investigator**
Research ID (ORCID)	0000-0003-0462-0138
Annual Person-month effort	**3.0**
Contribution to project	**Lead investigator on developing detection algorithms; other design activities include WiSAT module and seat sensor**

Name	*Chris Hanes*
Project role	**Research engineer**
Research ID (ORCID)	
Annual Person-month effort	**2.0**
Contribution to project	**Seat sensor interfacing; sensor characterization and validation**

Name	*Ashley Andrews*
Project role	**Research engineer**
Research ID (ORCID)	
Annual Person-month effort	**2.0**
Contribution to project	**sensor characterization and validation; human subject data collection and analysis**

Name	*JJ O'Brien*
Project role	**Graduate student**
Research ID (ORCID)	

Annual Person-month effort	**4**
Contribution to project	**Project management; WiSAT module design; WiSAT module to mobile phone communication; mobile phone app development; human subject data collection**

- **Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?**
  - Nothing to Report
- **What other organizations were involved as partners?**
  - **Organization:**

    University of Pittsburgh, School of Health and Rehabilitation Sciences
    Forbes Tower, Suite 5044
    Pittsburgh, PA 15260
    Partner PI: Tricia Karg

    - **Partner's contribution to the projec**t
      As defined in the scope of work, YR1 effort from the University of Pittsburgh focused on fully defining the pre-clinical trial in advance of applying for IRB and HRPO (DoD) review. All this effort is in advance of any engagement with potential participants and is required to process the required approvals.
    - **Financial support** : YR1 funding of $27842
    - **In-kind support**: none, in YR1
    - **Facilities:** no specialized facilities required for effort in YR1
    - **Collaboration:** Partner staff participated in conference calls and email exchanges as a part of developing the protocol and IRB
    - **Personnel exchanges**: none

  - **Organization:**

    VA Center of Innovation for Complex Chronic Healthcare (CINCCH)
    Edward Hines, Jr. Hospital
    Hines IL 60141
    Partner PI: Marylou Guihan

  - **Partner's contribution to the projec**t: Partner contributed to defining the pre-clinical protocol and overall discussions of WiSAT design
    - **Financial support :** none in YR1
    - **In-kind support**: none
    - **Facilities** *none in YR1*

- **Collaboration** Partner staff participated in conference calls and email exchanges as a part of developing the protocol and IRB
- **Personnel exchanges** *none*
- **Other.**
-

8. **APPENDICES:**

Appendix 1. Specification Table

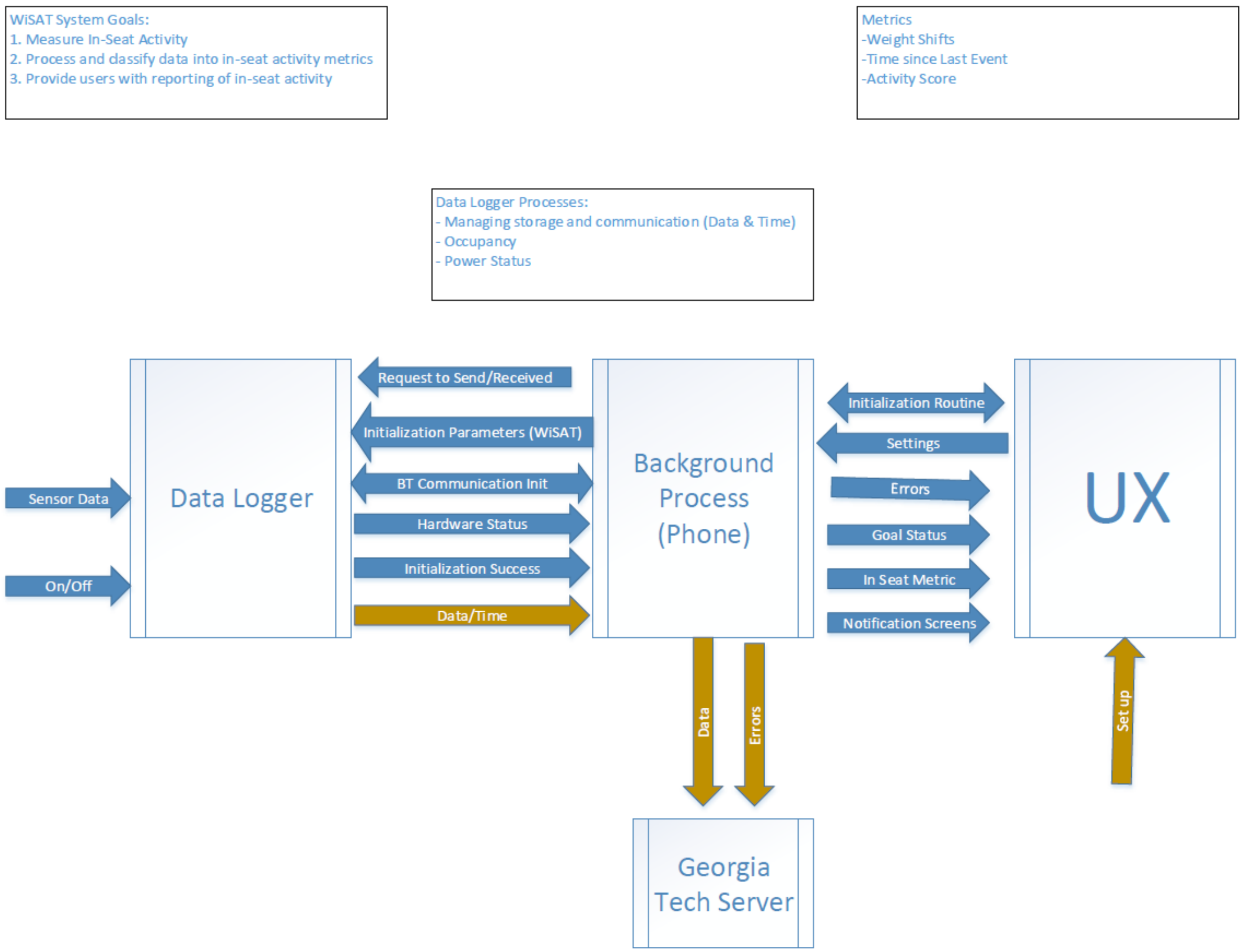
	Minimum requirements	**V2 Desired requirements and/or considerations**	**V3 Design requirements and/or considerations**
Enclosure			
Form factor	2x3x ½	Existing case is off-the-shelf: 2 ¾ x 1 7/8 x ¾"	Current case to be deployed in V3
Case and connectors	Seat sensor will use a locking connector at the case or via pig-tail. An optional extension cable will allow for an increased wire length between the sensor mat and the datalogger.	The unit has the option to be charged either through a micro-USB port (accessible by removing the unit from the wheelchair cushion) or through an inductive charging module. The inductive charging module's receiver is embedded inside the datalogger case.	The module's inductive charging transmitter will attach externally through a magnetic fastener to the datalogger (through the wheelchair cushion fabric) Charging and communication connector may use a water resistant USB connector We are currently investigating options for connectors.
Electronic Components			

Processor	Microprocessor: Atmel SAM3U Random Access Memory (RAM): In V2, the internal SAM3U RAM will be used.	The Atmel SAM3U replaced the SAM3S processor in WiSAT V2.	Same as V2
Battery life	Single 500 mAh battery 2 days with expected use of 12 hours per day	3.7V 500 mAh Lithium-Ion battery	1 week or more would be desirable
Indicators and on-off switch	V2 & V3 WiSAT includes on-off switch & power indicator and data indicator	Same as Min. Requirements	One or more indicators may be eliminated in final V3 module
Pressure Sensors	Six pressure sensors positioned on a 15" x 15" mat	Six individual Tekscan FlexiForce A502 Sensors	Same as V2 but with the six sensors embedded in a polyester mat
Datalogger internal Calibration	Internal Op-Amp Circuit	512 kOhms 2200 pF resistors	Same as V2
Data and Communication Protocols			
Communication	Bluetooth 4.0 Low-Energy (Telit 53330-02)	We defined an API to allow the mobile application to communicate with the data module via Bluetooth 4.0 Low-Energy. The API allows data to be sent batched or as a continuous stream upon request. Data will be serialized as JSON objects and will include sensor data, hardware system status, and battery life information.	Final communication requirements for V3 will be defined after testing V2 and creating mobile device app. This will be evaluated by collecting data into a prototype mobile app from the V2 unit through the Bluetooth API .

Data storage	8 GB of Flash memory to accommodate situation when phone and user are separated;	Flat file storage	Upgrade to SAM4S processor is unlikely; as a result, an SQLite database will not be deployed; The API for data module to mobile phone communication will remain the same whether SQLite is implemented or not.
Data Access/Transmission	Data will be stored as JavaScript Object Notation (JSON)	JSON data will be stored in flat files and accessed via USB or through the Bluetooth API	JSON data will be stored in flat files.
On-board processing	Occupancy on-board	Currently does not calculate occupancy	Occupancy and sensor drift on-board
User management	With a 2 day life, instructions will be for user to charge daily. Charging options are described in "Case and Connectors"	Inductive is deployed in V2; micro USB charging remains as back-up Mobile app will display a battery level of device based on information received from the module	
System Status	System status will be transmitted to the mobile app upon request	System status (error states, battery life, etc) are appended to each batched JSON data file.	Same as V2
Firmware			
Firmware	Proprietary Gulf Coast Data Concepts firmware and operating system	Same as Min. Requirements	Same as Min. Requirements

APPENDIX 2

Mobile Phone App Flow Diagram



APPENDIX 3: UI Screens- initial renderings