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CATEGORIZATION OF CONSTRUCTION TASKS FOR ROBOTICS USING LEAN VS VALUE-ADDED EFFECTIVENESS FRAMEWORK

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ABSTRACT

Robotics and automation are still considered a novelty in the U.S. construction industry, as compared to manufacturing, despite its proven advantages for production. Due to the continuing advancement of technology needed, there are limited applications of robotics in construction to date. To better identify the potential tasks that would benefit from the use of robotics on construction sites, we consider methods for assessing the craft labor tasks that occur in construction. In this paper, we decompose construction tasks of an observed activity of installation of stone veneer system and compared two systems of categorizing the construction tasks based on value added assessment and lean (waste) assessment of tasks. The analysis compares the two categorization systems using a matrix which highlights consistency in the alignment of value adding tasks, such as final placement, as well as ineffective tasks with type two muda, but discrepancies emerge regarding the idea of contributory tasks related to logistical support of construction activities. The focus of the discussion is derived from the intersection of contributory tasks with type one muda tasks. The contributory tasks offer an opportunity to reduce the use of craft labor for wasteful tasks elimination by leveraging automation and robotics.

KEYWORDS

Wastes, value, lean, construction tasks categorization.

INTRODUCTION

In the US construction industry adoption of robotics and automation has begun but is still in its infancy compared to Japan where the first construction robots appeared on sites in 1980s (Bock, 2007). With the current state of US construction industry's shortcomings in productivity, safety, and availability of labor, robots and automation offer at least a partial solution. The primary principle of adopting lean is to avoid and reduce waste and non-value adding activities. However, the nature of construction projects, with in situ work specific to the site of a given facility, creates challenges for

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ensuring efficient and value-added production to the extent seen in manufacturing contexts. With automation and robotics performing as the actors instead of human workforce in future, their deployment could be used to allow the craft labor to focus their efforts on the value-adding tasks for delivering a given project or could further hamper production and increase the waste if applied poorly.

Waste reduction has still not succeeded in the construction industry (Koskela & Bolviken, 2016). To effectively study the application of robotics for the purpose of reducing waste in craft labor tasks in construction, the tasks need to be decomposed in sufficient detail to assess the sub-tasks for a given construction activity for the level robots would contribute. Wastes could also be classified into seven types, compiled by Ohno and Bodek (1988) and Lai et al. (2019) and the type of Muda (Womack & Jones, 1996).

In this paper we utilize two existing methods of classifying the construction sub-tasks. The first was value added assessment of construction tasks, introduced by Pregenzer et al. (1999) to build upon the classical productivity research emerging from the construction domain. The second categorizes them by the commonly used seven types of wastes, as well as including recognition of value-adding tasks. A time study of installation of stone veneer as part of façade system of a construction project was conducted. After defining the decomposition using the two classifications, they are cross compared using a matrix framework to highlight discrepancies in how tasks are categorized under the parallel systems in pursuit of a framework for identifying tasks appropriate for leveraging robotics and automation.

LITERATURE REVIEW

The construction industry, with its inherited characteristics or peculiarities of site production, temporary organization, and bespoke designs (Vrijhoef & Koskela, 2005) is slow to adopt technology, traditionally unsafe and known for its low productivity and quality challenges. The nature of in situ construction industry requires balancing logistical support to bring all materials, labor, and equipment to a project with the effort to perform on the on-site work efficiently. A per Chang et al. (2004) the nature of construction industry resembles a unit production system dependent still mostly on jobsite activities with small batches of production and inherent with uniqueness of its projects due to varying needs and requirements of owners and designers. Research has pointed to numerous solutions like computer integrated construction, off-site and modular construction, automation and robotics, immersive technologies, and lean construction to overcome these problems.

Automated systems in the Japanese construction industry have increased the productivity, operator safety and work quality (Taylor et al., 2003). In construction, automation and robotics can be helpful in improving the quality of work thus adding value and reducing the wastes. Llale et al. (2019) conducted a more recent review of the advantages and disadvantages of the use of automation and robotics for the South African construction industry which revealed the potential of increased safety, productivity, and sustainability. However, the prioritization of tasks specific to site construction has not yet been identified.

Lean construction is formulated on the principles of lean production based upon the realization of the shortcomings of traditional project management (Ballard et al. 2007). Lean principles that were developed for the manufacturing industry have been adopted for the construction industry. As per literature review by Babalola et al. (2019) the predominant purpose of lean methods is to utilize minimum resources and efforts to attain maximum benefits and value for the customer. Lean Construction generates the product by maximizing value and minimizing waste while considering the construction project as a temporary production system (Ballard & Howell, 2003). Waste reduction is the core emphasis of lean. Within that approach, waste is defined as anything that does not add value. As per Porter (1985), "Value is what buyers are willing to pay" and as per Bolviken et al. (2014), "value is the wanted output, the usefulness of the product, functionality, utility and benefit and it is for the customer or client." Waste reduction and value generation are closely but inversely related. Identifying the wastes and then decreasing or removing them would be tantamount to adding value in a construction project. In construction there is a significant amount of waste that stays hidden, unworkable and is caused by rework or non-value adding activities, such as waiting, moving, accidents and repeated activities (Koskela, 1992).

TASK CATEGORIZATION AS PER SEVEN TYPES OF WASTES

Compiled definitions of the seven types of waste in lean manufacturing is shown in Table 1 based upon Ohno and Bodek (1988) and Lai et al. (2019). Construction sub-tasks could be categorized into the types of waste using this classification. The characterization of wastes supports concept within continuous improvement, it offers a lens for identifying tasks that can be adjusted or removed to improve the value-adding emphasis of production steps.

Table 1: Seven types of Wastes, based upon Ohno and Bodek (1988) and Lai et al. (2019)

Waste	Summarized Definitions
Over-production	Producing too much/ when not needed / without actual orders
Waiting	Waste of time or delays, idling or unable to process due to unforeseen reasons
Transportation	Waste of movement of material or product unessential to the production process
Over-processing	Unnecessary steps taken to produce the product, produce anything that is not valued / required nu customer
Inventory	Waste due to excess work in progress (WIP) / stocks / materials finish or unfinished
Unnecessary motion	Waste due to movements that do not add value to the product
Defects	Waste from making products that is defective, unacceptable quality or require corrective rework to be accepted by customer

TASK CATEGORIZATION AS PER LEAN ASSESSMENT

Womack and Jones (1996) provided a different perspective to study the value stream by decomposing the value stream into different actions (tasks) and segregating them in value adding or muda. Muda is the Japanese word for wastefulness. Within this classification there are three categories; (1) Value adding – which create value as required by the customer; (2) Type One Muda – which are steps that do not create value but are required for the process and cannot be excluded; and (3) Type Two Muda – which do not create value as required by the customer ad can be directly removed.

TASK CATEGORIZATION USING VALUE ADDED ASSESSMENT

Building upon traditional construction categorization, this method defined by Pregenzer et al. (1999) of classifying construction activities leverages the previous works of Thomas (1983) and Oglesby et al. (1989) by introducing contributory and ineffective tasks. The resulting value-added effectiveness framework (VAEF) contains a set of nine rules, demonstrated in Figure 1. The VAEF can be used to assist in identification of value adding, contributory and ineffective tasks. Tasks that do not qualify for the specific decision node keep going down the chain and settle at the bottom in the category of ineffective tasks.

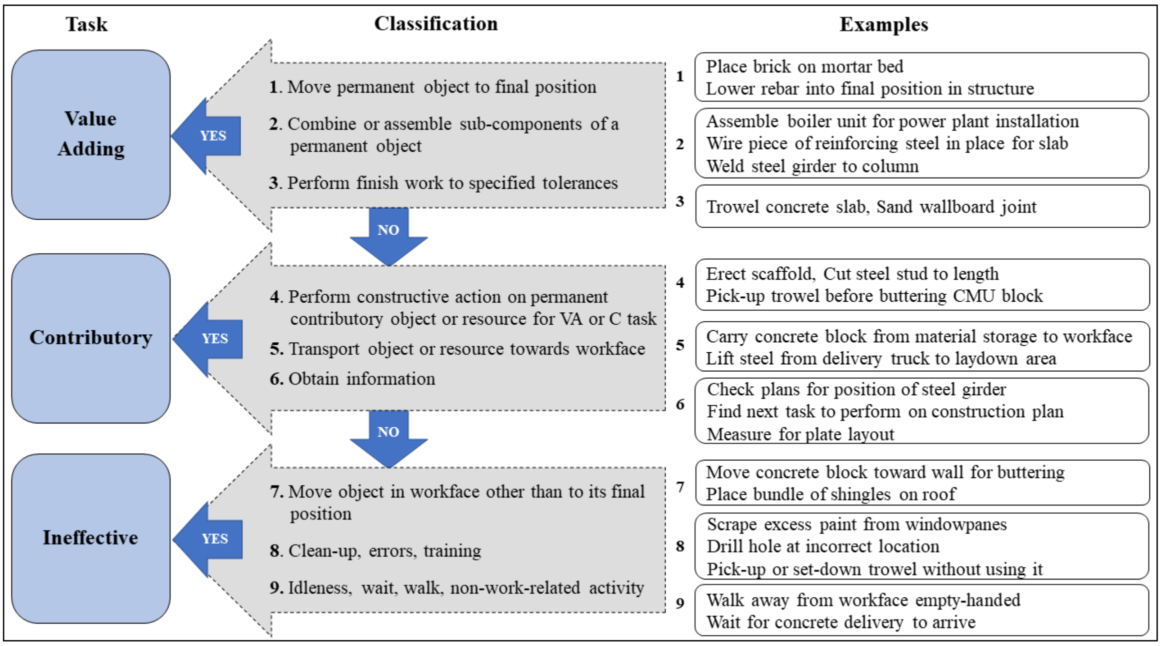

Figure 1: VAEF Flow Chart for Nine Decision Nodes (from Pregenzer et al. 1999)

METHODOLOGY

TEST CASE

To compare the application of these alternative classification systems to construction tasks, a test case was performed for the installation of a stone veneer system as part of the façade works at a residential building project. The author used a handheld video recorder to observe and record video of the workers installing stone veneer system on a local project. A subset of the recording and resulting analysis are presented using 10 minutes and 22 seconds (622 seconds) of the observed work. The limitation with the data set is the small sample size of analyzed data; 4 minutes and 23 seconds (263 seconds) for first worker and 5 minutes and 39 second (339 seconds) for the second worker. Some data is labeled as "out of view" because of the inability to capture both workers simultaneously in the video recording frame due to the distance between the workers. While the author is aware of the general tasks being performed, the classification was limited to the observed video data. For calculation purposes, the out of view portions for both workers were neglected from data sets to be consistent in our approach. While the sample is small, the purpose is not to develop a rigorous analysis of the production process, but to discuss test and compare the systems of time classification. The first worker was working at the ground level and performing sub-tasks of picking and cutting stone, checking placement of stone on wall, applying mortar to the stone, attaching the stone veneer to the wall and necessary movements in between. The second worker was working in a scissor lift at a raised elevation to prepare the mortar scratch coat for the future installation of stone. Each sub-task was decomposed into the lowest level of craft labor activity, with durations of movement down to a two-seconds duration for a partial activity of a worker to split apart their movement, cutting, and transportation sub-tasks for a given installation sequence.

All sub-tasks were categorized using both classification systems i.e., using VAEF for value-added assessment (VA - value adding tasks, C - contributory tasks and I - ineffective tasks), the seven types of waste and the type of action (lean assessment). The percentages of time spent by each worker for value added assessment tasks (value adding, contributory, and ineffective) and lean assessment of tasks (value adding, type one muda, and type two muda) were also calculated.

RESULTS

Data was time-coded from the videotape for both workers and decomposed into sub-tasks as shown in Table 2 and Table 3.

Table 2: Task Categorization and Assessment for Worker 1

Time (mm:ss)	Sub-tasks	Time (secs)	VAEF	Type of Waste	Muda
00:00 - 01:02	Out of view	62	-	-	-
01:02 - 01:07	Scrape off excess mortar from stone	5	VA	Over-production	One
01:07 - 01:14	Move for stone pickup	7	I	Transportation	One
01:14 - 01:26	Pick up stone & cut	12	C	VA	VA
01:26 - 01:38	Apply mortar to stone	12	VA	Over-processing	One
01:38 - 01:40	Move to wall to attach stone	2	C	Transportation	One
01:40 - 01:57	Attach stone to wall	17	VA	VA	VA
01:57 - 01:59	Pickup stone & move to mortar location	2	C	Transportation	One
01:59 - 02:08	Apply mortar to stone	9	VA	Over-processing	One
02:08 - 02:11	Move to wall to attach stone	3	C	Transportation	One
02:11 - 02:28	Attach stone to wall	17	VA	VA	VA
02:28 - 02:35	Scrape off excess mortar from stone	7	VA	Over production	One
02:35 - 02:50	Pick & check stone placement on wall	15	C	Over-processing	Two
02:50 - 03:04	Cut stone	14	C	VA	VA
03:04 - 03:10	Check stone placement on wall (rework)	6	I	Over-processing	Two
03:10 - 03:15	Cut stone (rework)	5	I	Over-processing	Two
03:15 - 03:20	Check stone placement on wall (rework)	5	I	Over-processing	Two
03:20 - 03:27	Cut stone (rework)	7	I	Over-processing	Two
03:27 - 03:34	Check stone placement on wall (rework)	7	I	Over-processing	Two
03:34 - 03:48	Cut stone (rework)	14	I	Over-processing	Two

03:48 - 03:52	Check stone placement on wall (rework)	4	I	Over-processing	Two
03:52 - 03:55	Cut stone (rework)	3	I	Over-processing	Two
03:55 - 04:02	Check stone placement on wall (rework)	7	I	Over-processing	Two
04:02 - 04:12	Cut stone (rework)	10	I	Over-processing	Two
04:12 - 05:58	Out of view	106	-	-	-
05:58 - 06:12	Check stone placement on wall	14	C	Over-processing	Two
06:12 - 07:04	Out of view	52	-	-	-
07:04 - 07:09	Check stone placement on wall	5	C	Over-processing	Two
07:09 - 07:13	Cut stone	4	C	VA	VA
07:13 - 07:21	Check stone placement on wall (rework)	8	I	Over-processing	Two
07:21 - 07:30	Cut stone (rework)	9	I	Over-processing	Two
07:30 - 07:38	Check stone placement on wall (rework)	8	I	Over-processing	Two
07:38 - 07:51	Cut stone (rework)	13	I	Over-processing	Two
07:51 - 07:54	Check stone placement on wall (rework)	3	I	Over-processing	Two
07:54 - 08:15	Out of view	21	-	-	-
08:15 - 08:24	Cut stone	9	C	VA	VA
08:24 - 10:22	Out of view	118	-	-	-

Note: Type One and Type Two are Muda; VA = Value Adding; C = Contributory; I = Ineffective.

The craft worker was working to install stone veneer, with their time spent cutting the stone to size, checking the fit into the desired location, then applying mortar and placing the stone. Using the VAEF classification, 67 seconds (25%) of the worker's time was considered value adding, 80 seconds (30%) were contributory, and the remaining 116 seconds (44%) were ineffective. However, when using the lean approach to identifying waste, 28% was value-adding; 18% of tasks were type one muda that was spent mostly in the application and removal of excess mortar, as well as some time in the transport task of the stones. Approximately 54% of tasks were type two muda with most of that time being over-processing or re-work for correcting the dimensional cutting of stone that did not fit in the first attempt.

The second worker was working on a scissor lift to prepare the surface material for the future installation of the stone veneer. Using the VAEF classification, 135 seconds (40%) of the workers time was considered value adding, 155 seconds (46%) were contributory, and the remaining 49 seconds (14%) were ineffective. Using the lean approach to identifying waste, none of the task was value-adding; 86% were type one muda – primarily when the working was performing the 'scratch coat' task of using a brush to scratch the mortar that was already applied at the workface. This is a necessary step in the process of applying the stone for this specific process and material, but the task of manually scratching the entire preparatory surface is not specifically value-adding for the final product; and 14% were type two muda when the worker appeared to be 'wandering around' the site for a period.

Table 3: Task Categorization and Assessment for Worker 2

Time (mm:ss)	Sub-tasks	Time (secs)	VAEF	Type of Waste	Muda
00:00 - 00:50	Apply mortar scratch coat	50	VA	Over-processing	One
00:50 - 02:17	Out of view	87	-	-	-
02:17 - 02:40	Apply mortar scratch coat	23	VA	Over-processing	One
02:40 - 02:52	Move scaffold up	12	C	Transportation	One
02:52 - 03:06	Apply mortar scratch coat	14	VA	Over-processing	One
03:06 -03:15	Move scaffold up	9	C	Transportation	One
03:15 - 03:54	Apply mortar scratch coat	39	VA	Over-processing	One
03:54 - 04:03	Move scaffold up	9	C	Transportation	One
04:03 - 04:12	Apply mortar scratch coat	9	VA	Over-processing	One
04:12 - 06:44	Out of view	152	-	-	-
06:44 -07:33	Unnecessary walk	49	I	Unnecessary Motion	Two
07:33 - 07:54	Out of view	21	-	-	-
07:54 - 08:04	Climb on scissor lift	10	C	Over-processing	One
08:04 - 08:27	Out of view	23	-	-	-
08:27 - 10:22	Move scissor lift and set up	115	C	Transportation	One

Note: Type One and Type Two are Muda; VA = Value Adding; C = Contributory; I = Ineffective

DISCUSSION

When comparing the tasks, categories were plotted, as shown in Figure 2, to highlight the differences in categorization between the two frameworks for assessing the craft worker time.

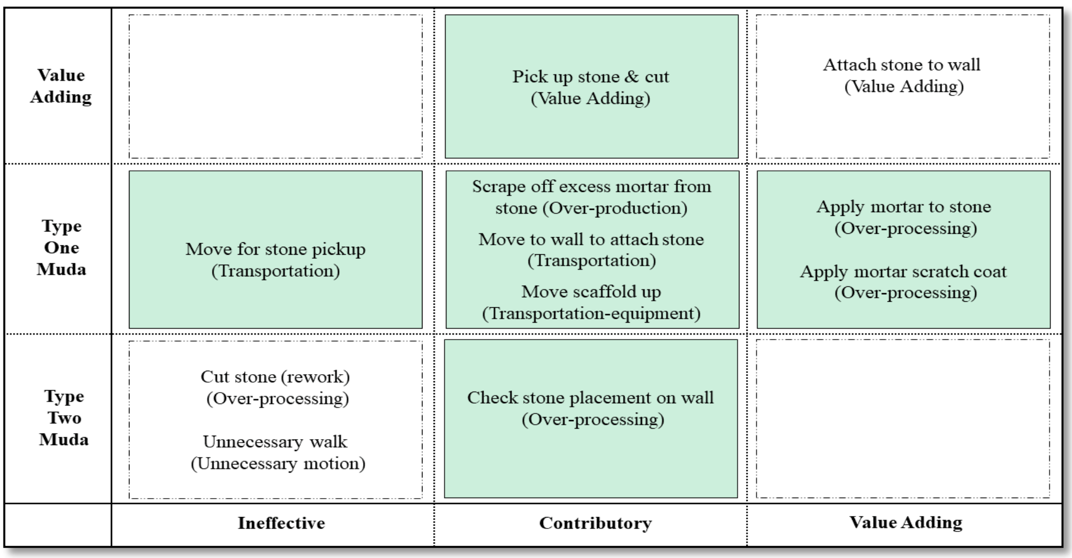

Figure 2: Matrix for comparing Task Categorization and Assessment

The horizontal axis is based upon Pregenzer et al. (1999), with ineffective tasks on the left and moving to the value-adding tasks on the right. The vertical axis is based upon the lean categories, starting with type two muda at the bottom, type one muda in the middle, and value adding at the top. When cross comparing, some of the tasks are closely aligned – ineffective tasks and type two muda generally match up quite consistently (bottom left): when the worker is walking without purpose, it is both ineffective and meets the type two waste classification. Similarly, but at the opposite end of the scale, the value-adding tasks related to the final placement of materials generally align (top right). The placement of work provides value in both classification systems. Further, there are two areas do not have any tasks. None of the Value adding tasks, per the lean categorization, matched the ineffective categorization in the VAEF framework (top left). Similarly, none of the type two muda matched the value adding category of the VAEF framework (bottom right).

However, when specifically focusing on tasks that may offer some discrepancy between the two classifications, the first areas to highlight are those noted in the VAEF framework as contributory tasks that address some of the necessary logistical tasks of supporting construction work that do not directly contribute to the value of the finished product. Within the lean framework, tasks add value or do not add value (waste). This middle column of tasks has elements that were categorized into each of the lean categories. For example. when the worker is checking stone placement on the wall prior to cutting and applying mortar it is considered type two muda as it is not creating any value and could arguably be eliminated if the stones were already pre-cut to correct sizes, but contributory because the worker needs to check the size of stone to assess how much stone cutting is required. It is also considered over-processing as per the type of waste.

Scraping off excess mortar falls in the category of type one muda and contributory. It is a required step arising out of the use of mortar as the binding material but does not creating value rather is considered over-production, but due to the nature of the use of mortar as a material is nearly impossible to remove in its entirety. Similarly, to perform work at a higher elevation, the worker needs to move the scissor lift to accommodate the location of the scratch mortar work at elevation, which is a required step but does not add value to the final product, so it is considered waste. Picking stone and cutting fits in the category of value adding as per lean assessment of tasks because it adds value to the final product but is contributory because it is a constructive action on a permanent object.

In addition to challenges in the cross-comparison, there were areas that were difficult to group properly as per classification – for example, the value-added assessment has explicit categorizations (per Figure 1) for tasks like cutting; but the scratch coat task is not an explicit example and appear to fall between their third and fourth decision nodes of the flowchart. It is not explicitly 'finish work' from a finished-product perspective, suggesting it is contributory, however it is part of the finished system – suggesting it may be value-adding by their criteria. This also poses a potential research limitation in the ability to consistently categorize tasks that may not match the definitions provided.

Within the lean analysis, there was similar difficulty in trying to determine how much movement was 'value-adding' vs wasteful when the worker was moving stone to its final location. Arguably, if the stockpile is closer to the workface, there is less wasted movement by the worker in selecting and placing the stone. However, there is value in having the stone moved to its final location for the ultimate customer. Similarly, when the worker moves to pick stone there is 'some' level of necessary movement to move to pick up a stone, but there is some unnecessary movement that ties back to where the stone is placed. This highlights one of the challenges of using the lean waste structure to the logistical aspects of task assessment in construction. In the ideal of single-piece flow, each stone would be placed immediately upon arrival at the site – however the logistics of delivering smaller materials in this manner could become cost-prohibitive and would introduce waste in the transport. Thus, construction's distinction from manufacturing as site-specific must consider how to address the 'contributory' nature of the logistical tasks as necessary and value-adding in the importance of the location of the project to the client. However, this contributory value must be balanced with the potential waste introduced from excess inventory on site, as well as poorly located materials, that created added movement, over-processing, and potential damage to stored materials among many other potential areas of lost value defined by the seven types used.

Returning to the second reason for this analysis is the opportunity of how to reduce the inherent wastes through the consideration of automation and robotics. To analyze this aspect, we updated the matrix by plotting the time and percentage of all intersections for both workers as shown in Figure 3.

	Ineffective	Contributory	Value Adding
Value Adding	0	Worker 1 – 39 Secs (14.8%) Worker 2 – 0 Secs	Worker 1 – 34 Secs (14%) Worker 2 – 0 Secs
Type One Muda	Worker 1 – 7 Secs (2.6%) Worker 2 – 0 Secs	Worker 1 – 7 Secs (2.6%) Worker 2 – 155 Secs (46%)	Worker 1 – 33 Secs (12.5%) Worker 2 – 135 Secs (39.8%)
Type Two Muda	Worker 1 – 109 Secs (41%) Worker 2 – 49 Secs (14.5%)	Worker 1 – 34 Secs (13%) Worker 2 – 0 Secs	0

Figure 3: Task Categorization and Assessment for Worker 1 and Worker 2

First, the tasks that occur at the intersection of the ineffective and type two muda like unnecessary walking and rework for unprecise stone cutting should be removed which is the core emphasis of lean. Also, the high value tasks that address the unique attributes of construction projects at the intersection of the value-adding categorizations like attaching stone to wall should likely be prioritized for continued craft involvement.

Analyzing worker 1, we can see that the tasks at the intersection of contributory and type one muda totals 45%, which is a considerable amount of time when the worker is not performing value-adding tasks. Similarly analyzing worker 2, we find that tasks at the intersection of contributory and type one muda total about 85% which is a high amount of waste. This could also be helped using automation and robotics and benefit in savings in terms of labor costs. In the tradition of robotic adoption, transport of materials between workstations in manufacturing were one of the earliest uses. With the forecasted shortfall of skilled workers, finding a scheme for appropriate uses of robots on construction sites will become an urgent need to balance human-robot construction crews. Labor intensive and repetitive but low-value tasks, such as the step of performing the scratch coat, serves as example opportunity where the task is necessary for the specific system but offers limited value-add to the overall facility. Further, other opportunities for identifying tasks to de-prioritize for craft, such as methods that leads to repetitive stress injuries in workers, should also be considered.

The contributory tasks under the VAEF framework seem to offer a valuable lens for tasks that could reduce the logistical burden and repetitive tasks, such as material movement, that robots could support. However, there are several areas that were considered waste by use of the lean categorization that should be removed, rather than transferring to a robot to perform, there is a potential challenge of creating more waste if robots are added but not thoughtfully planned. Similarly, there were some tasks, such as the scratch coat tasks, that were arguably 'value adding' that might be better suited for application of robotics due to the lower value in the use of craft labor and potential negative impacts on the worker health – such as repetitive stress injuries. These tasks appear to offer increased effectiveness for the craft labor time, for example robots could be better positioned to provide 'just-in-time' material to workers that would reduce site congestion as well as excess transport and movement tasks by workers or congested inventory. There is potential waste in tasks at the intersection of contributory and type one muda (45% for worker 1 and 85% for worker 2) which is hard to remove due to the nature of the tasks but could potentially reduce the cost to projects or mitigate worker shortfalls through the implementation of automation and robotics.

CONCLUSIONS

In this paper an effort was undertaken to highlight the shortcomings of construction task assessment using value added assessment (VAEF), as well as the seven types of wastes for an observed stone veneer installation activity for consideration of construction robotics. The shortcomings are mostly due to the nature of construction industry with numerous contributory tasks that span the types of waste as per lean assessment of tasks. The correct identification and categorization of construction tasks as per the assessment systems is challenging with identified discrepancies between the two types of assessment primarily related to logistical tasks necessary at construction sites. Applying the core principle of lean to eliminate the type two muda and ineffective tasks shown in the bottom row of the matrix and letting the value adding tasks in the top row of the matrix being performed by the human craft, there still exists significant waste at the intersection of contributory and type one muda tasks. This waste demands removal too and potentially could be achieved by utilizing automation and robotics to tackle these tasks which are repetitive and add very little value

In this paper some inherent wastes lying at the intersection of contributory and type one muda tasks have been highlighted and one of the potential solutions to use automation and robotics suggested. Future work will focus on more details about how these contributory and type one muda tasks could be eliminated by analyzing multiple solutions like prefabrication, modularization and introducing robotics and automation.

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