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ASSESSMENT OF THE POSSIBILITIES OF USING THE QFD METHOD AND SELECTED LEAN MANUFACTURING TOOLS IN THE DESIGN AND OPTIMIZATION OF THE PRODUCTION OF CONCRETE RAISED GARDEN BEDS

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Abstract:
The aim of the work was to assess the possibilities of using the QFD method and selected Lean Manufacturing tools in the process of designing and optimizing the production of concrete raised garden beds. The theoretical part discussed the basics of the QFD methodology and selected Lean tools. The research was conducted in a small enterprise producing concrete products for construction. In the first part of the analysis, the QFD method was used as a tool to identify customer needs regarding concrete raised garden beds. The information collected as a "house of quality" served as a starting point for further research using selected Lean Manufacturing tools such as 5S Practices, the SMED method, the Kaizen philosophy and FMEA method. The results indicated that combining the QFD method with Lean Manufacturing tools can increase the quality of the offered product, better suited to the needs of end users and improve its production process in terms of quality, efficiency and costs.

Key words: concrete raised garden beds, QFD method, lean manufacturing, 5S practices, SMED method, Kaizen, FMEA method

INTRODUCTION

The modern market for garden products, including concrete modules such as raised beds, is characterized by increasing competitiveness and increasing customer expectations in terms of aesthetics, durability and functionality. Raised concrete beds are becoming increasingly popular due to their many advantages. The most important of them include: easier access to planted vegetables or flowers thanks to their height, reduced risk of trampling by animals or playing children, durability and resistance to weather conditions, aesthetics, the possibility of shaping the space on the plot. Understanding customer needs is therefore becoming a key element of effective design and offering products with high utility value.

One of the tools that enable the systematic consideration of the customer's voice [1, 2] in the product design process is the QFD method – Quality Function Deployment, also known as Quality Function Development or Alignment, or House of Quality [3, 4, 5]. QFD was first described by Yoji Akao in the 1960s in Japan [6, 7], as part of "Total Quality Control", as a tool supporting product development in the automotive industry [6]. Using the QFD method, market requirements for a product or service can be translated into the technical conditions that the company producing it must meet. This applies to each stage of development (design, production, sales, service) [8]. The QFD method has many advantages [10, 11, 12]. The company can better understand its strengths and weaknesses compared to the competition, the voice of a potential customer can be considered already in the design phase, thanks to which the final product can be better designed to meet the customer's needs, quality costs can be better planned and the product development cycle time is shortened. According to [13], the QFD method consists of 8 stages.

On the other hand, effective production of concrete beds requires not only knowledge of customer expectations, but also their translation into specific actions in the production area. In this context, Lean Manufacturing tools are useful, the aim of which is to eliminate waste and increase process efficiency [14, 15].

5S Practices are used to simplify, organize and improve safety [16, 17] at work stations. Thanks to these practices, the work station (defined in Japanese as gemba) is clean, organized, efficient and safe [18, 19]. The introduction of 5S in a given company has a positive effect not only on the work station, but also on the employee. A positive approach to work and openness to change are developed. The employee performs their work in an environment that is friendly to them, which makes work enjoyable, less burdensome and, above all, effective [20, 21]. 5S practices consist of 5 stages [22, 23, 24]: Seri (Sort), Seiton (Straighten), Seiso (Shine), Standardize (Seiketsu), Sustain (Shitsuke).

The SMED method aims to shorten the changeover time in a time not longer than the time given in minutes, the result of which is a single digit, i.e. less than 10 minutes. The division of changeovers into external (performed when the machine is in motion) and internal (performed only when the machines are stationary) allows to separate and then convert internal changeovers to external - this allows to significantly improve the changeover process, bringing even 90% reduction of the machine idle time [25, 26, 27].

Kaizen is a management philosophy originating from Japan, which is closely related to Japanese culture and mentality. In practice, however, it is a set of "hard" and effective tools for introducing and maintaining changes in the processes and resources of an organization [28, 29]. Kaizen is a low-cost, common-sense and creative approach to management. It is an endless process of improving the quality of a company and a product.

The FMEA (Failure Mode and Effect Analysis) method is a quality management method developed in the USA by NASA in the 1960s for the Apollo program [30, 31]. FMEA is based on early detection, assessment and prevention of: potential errors and their causes and effects. The main goals of FMEA are the constant and consistent elimination of inconsistencies and defects in a product or production process by identifying the real causes of their occurrence and applying appropriate preventive measures [32]. The FMEA method consists of two types of analyses: product/design FMEA and process FMEA [33]. FMEA is successfully used in the automotive [34, 35], chemical [36, 37], aerospace [38, 39], electronics industries [40, 41], but it can also be used in other industries and even services [42].

The paper attempts to combine two approaches – customer-oriented design (QFD method) and process optimization (Lean) – in the context of the production of concrete raised garden beds. The analysis is based on data obtained from customers, distributors, observations and measurements conducted at selected production stations in the company. The paper aims to demonstrate and assess whether the use of the QFD method and selected Lean Manufacturing tools will be helpful in the process of designing and optimizing the production of concrete garden beds. The novelty of the paper is the combination of the QFD method with Lean Manufacturing tools in the sector of microenterprises producing concrete products for construction. A certain limitation of the paper is the small research scale – one company, a limited sample of customers and the lack of and lack of comparison with competitors (one of the stages of the QFD method).

METHODOLOGY

The research was conducted in a small company located in southern Poland, specializing in the production of concrete products for construction, including raised garden beds. The company employs 21 people, including 10 production workers, and operates on the local and regional market. Annual production of beds is approximately 3500 pieces.

The company encountered the problem of growing competition from large garden chains and unstable seasonal demand. In order to improve its market position, it was decided to better understand customer expectations and adapt technical requirements to them, as well as optimize the internal production process to reduce costs and increase product quality.

For this purpose, the QFD method and selected Lean Manufacturing tools were used: 5S practices, the SMED method, the Kaizen philosophy and the FMEA method.

In the first step, a qualitative study was conducted among retail customers and distributors. The following methods were used:

- in-depth interviews with 10 individual customers (garden owners),
- an online survey, sent via local gardening groups (Facebook), which was completed by 52 people,
- interviews with 8 distributors (3 local garden centers).

Data from interviews and surveys were collected over several weeks, preceded by preliminary market analysis and customer segmentation.

Based on the initial analysis, it was determined that the study population was mainly male, aged 30 to 45, with secondary and higher education. After identifying the population, summary lists were drawn up – it was decided to divide the study population into 2 groups of 35 people. Then, through drawing, 10 people were selected from each of these groups – in this way a representative group was created.

The qualitative responses in QFD analysis were transformed into measurable technical requirements.

RESULTS

The analysis using QFD method was carried out in 7 stages:

Stage – I is the identification of customer requirements (Voice of Customer).

In this stage, a representative group was asked the question: What features should an ideal concrete raised garden bed have in your opinion? Based on the data analysis, 15 most frequently repeated expectations and needs were identified, which are listed below:

1. Durability (garden beds should be resistant to weather conditions and the passage of time).
2. Aesthetic appearance (they should blend in well with the garden, modern or natural look).
3. Frost resistance (they should not crack in winter).
4. Ease of installation (possibility of self-assembly).
5. Safety of use (no sharp edges, stability).
6. Abrasion resistance (they should not wear out easily when in contact with tools).

7. No need for maintenance (the customer does not want to maintain them regularly).
8. Ecological nature of the material (environmentally friendly or recycled concrete).
9. Adjustment of dimensions (various sizes and shapes to choose from).
10. Stability after installation (they do not move or collapse).
11. Resistance to plants, e.g. roots (they should not crack under pressure).
12. Price adequate to quality (good price/quality ratio).
13. Possibility of multiple use, e.g. moving to another location.
14. Availability of colours/patterns (personalisation options or matching to the style of the garden).
15. Availability in stores (easy to purchase, also locally or online).

The requirements that respondents have before purchasing concrete raised garden beds are included in the quality house in area I.

Stage II – Determining the importance of customer requirements.

To implement this stage of the QFD method, a survey was conducted, which included all customer expectations and needs (requirements) regarding concrete raised garden beds. The next step was to ask a representative group to distribute a specified number of points (in the work it was assumed that it would be 100 points) for each requirement and to sum up these points. Then, the importance of each of these requirements was determined.

The requirement that received the highest number of points among the respondents was the requirement with the highest importance, while the requirements with the lowest number of points – with the lowest importance. A scale of 1 to 10 points was used for the needs of the work, where 1 means the least important requirement and 10 – the requirement with the highest importance.

The most points and thus the highest importance weight was given to requirements related to durability, frost resistance and price adequate to quality, as well as safety of use and stability after installation. The least importance was given to requirements regarding the possibility of multiple use and ecological nature of the material. The determination of the importance of customer requirements is presented in the area II house of quality.

Stage III – Determination of technical parameters of the selected product.

At this stage, the concrete raised garden beds were characterized from the designer's point of view by determining their technical parameters, which are presented below:

1. Compressive strength
2. Frost resistance
3. Surface hardness
4. Surface roughness
5. Weight of one concrete raised garden bed
6. Elasticity modulus
7. Abrasion resistance
8. Type and content of ecological admixtures
9. Dimensional accuracy
10. Dimensional stability over time
11. Type of surface
12. Resistance to root penetration
13. Production cost of one concrete raised garden bed
14. Number of available variants
15. Availability in retail chains

The house of quality in area III contains the technical parameters.

Stage IV is the determination of the relationship between the customer's requirements and technical parameters.

For the purposes of this work, specific symbols were adopted to indicate the strength of the relationship when it occurs between customer requirements and technical parameters.

● - strong relationship strength (9 points)
○ - medium relationship strength (3 points)
Δ - weak relationship strength (1 point)
none – no relationship.

The relationships between customer requirements and technical parameters are presented in area IV in the middle part of the house of quality.

Stage V is the assessment of the importance of technical parameters (area V of the house of quality).

The importance coefficients of technical parameters were calculated based on the formula [11]:

$$T_j = \sum_{i=1}^{l} W_i \, Z_{ij} \tag{1}$$

where:

T_j – importance of technical parameters,
W_i – importance coefficient of subsequent requirements "i",
Z_{ij} – coefficient of relationship between customer requirements "i" and technical parameters "j" and presented in area V of the quality house.

VI. Determination of the relationship between technical parameters (area VI of the house of quality).

The example uses the symbols presented below.

▲ – strong relationship strength (9 points)
▲ – medium relationship strength (3 points)
Δ – weak relationship strength (1 point)
none – no relationship.

VII. Target values of technical parameters

In the analyzed example, the target values of technical parameters are presented in the house of quality in area VII.

Figure 1 shows a quality house for concrete raised garden beds.

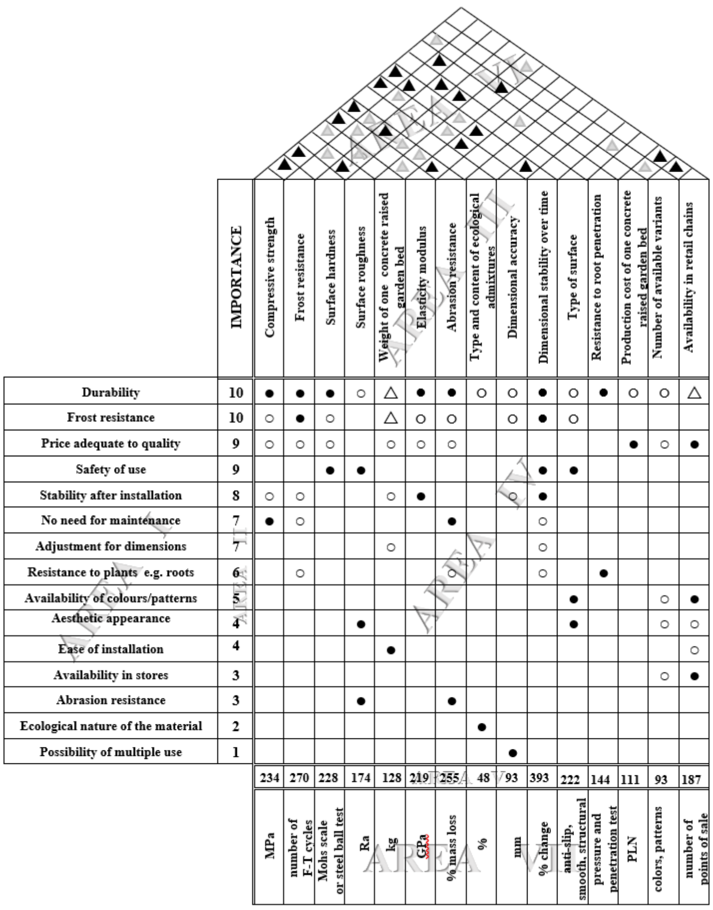

Fig. 1 Quality house for concrete raised garden beds

The House of Quality and its transparent structure allow us to see, among other things, which technical parameters, as well as customer requirements and technical parameters have the strongest relationships. Based on Figure 1, we can observe that:

– The strongest relationships between customer requirements and technical parameters (area IV of the quality house) occur, among others, between "durability" and "compressive strength" – the durability of the concrete raised garden bed largely depends on its resistance to mechanical forces, which translates into resistance to damage and wear. Another strong relationship is between "durability" and "frost resistance" – high resistance to freeze-thaw cycles is crucial in Polish climatic conditions and determines the longevity of the product. Strong relationship is also between "no need for maintenance" and "compressive strength" – a customer who expects no need for maintenance actually expects a durable, resistant and stable material, and this is directly related to high compressive strength and between "safety of use" and "surface hardness" – a hard but properly finished surface minimizes the risk of damage, but also injuries to the user. This is important for ensuring safe use.
– The strongest relationships between technical parameters (area VI of the house of quality) occur, among others, between "compressive strength" and "frost resistance" – their strong connection suggests that improving one of them can support the other, which is important in the context of changing climatic conditions. Strong relationship occurs also between "surface hardness" and "abrasion resistance" – the harder the surface, the less it is subject to abrasion, which directly translates into the aesthetics and durability of the product. Another strong relationship is between "dimensional stability over time" and "dimensional accuracy" – these parameters are jointly responsible for maintaining the shape and dimensions of the board during use – they are crucial for durable and aesthetic assembly. Strong relationship is also between "weight of one concrete raised garden bed" and "production cost of one concrete raised garden bed" – the lighter the board (less material), the lower the production cost. However, reducing the weight cannot be at the expense of strength – this relationship requires optimization activities.
– The highest importance factor (area V of the quality house) has technical parameters concerning, among others: "dimensional stability over time" – this is crucial for maintaining the durability and functionality of the flowerbed in the long term, especially when exposed to changing weather conditions and the action of plants. The importance factor is high also in "frost resistance" – this is a key parameter for climatic conditions in Poland – without an appropriate level of frost resistance, the boards may crack, which shortens their service life and negatively affects the safety of use.

– Based on the results presented in graphic form as the "House of Quality", the most important areas requiring intervention were indicated:
– "durability" and "frost resistance", strongly related to "compressive strength", "frost resistance", "surface hardness" and "abrasion resistance",
– "safety of use" and "stability after installation", dependent on, among others, "dimensional stability over time", and the use of Lean Manufacturing tools was proposed, which will help to increase the quality of the product and reduce production losses.

The first tool implemented in the surveyed company to improve dimensional accuracy, dimensional stability over time and safety of use was 5S Practices.

The station selected for analysis was where concrete raised garden beds are formed and poured – this is a key stage in the production process of concrete raised garden beds, because it affects the quality, dimensional accuracy and safety of the product.

Before implementing 5S Practices, this station consisted of, among others: 6 steel molds, an auxiliary table with tools, a container with concrete supplied from the mixer, manual tools for surface finishing, auxiliary materials and technical documentation and production orders.

The main problems at this station were: dirty molds and tools, which caused surface inaccuracies, lack of permanent storage places for tools, mess in documentation, and an excess of unnecessary items.

Activities within the individual stages of 5S included:

1. Seiri – Sort:
   – conducting an audit of the workstation,
   – removing all tools not used regularly,
   – throwing away old containers, used tools and expired chemicals.

As a result, only those elements that are necessary for daily work remained at the station.

2. Seiton – Straighten:
   – a shadow board was introduced to display all the elements necessary at a given workstation so that they were quickly and easily accessible to employees,
   – drawers for tools and chemicals were marked with a color,
   – magnetic holders were installed for frequently used tools,
   – production documentation was placed in a transparent binder hung at the station.

As a result, operators do not waste time looking for tools; each has its own place. Activities are performed faster and more precisely.

3. Seiso – Shine:
   – daily cleaning of molds, tools and work surfaces after the end of the shift,
   – responsibility for cleaning was assigned to a specific person (a different employee every week),
   – a control board was placed at the station saying "clean/to be cleaned".

It was observed that after implementing this stage, the number of plate surface defects decreased, and a mold not prepared for work was immediately detected.

4. Seiketsu – Standardize:
   – a checklist for checking the workstation (before, during and after work) was developed and placed in a visible place for employees,
   – a simple instruction regarding the “ideal workstation” was created in a visible place for employees, in the form of a photo,
   – a training in 5S Practices was conducted.

After this stage, it was observed that employees had introduced 5S principles as a daily routine and they were no longer a one-time activity.

5. Shitsuke – Sustain:
   – a “5S workstation leader” was appointed, who assesses and reports any non-conformities once a week,
   – a monthly 5S score and a reward system were introduced.

As a result, 5S became part of the organizational culture. Employee motivation and their involvement in maintaining quality increased.

Another Lean Manufacturing tool used in the company was the SMED method. It was used because reducing the changeover time directly affects the “production cost of one concrete raised garden bed” and “dimensional accuracy”, which are parameters indicated in the QFD analysis. The analysis was performed on the steel mold exchange and cleaning station between production series of different models of garden beds (e.g. with different dimensions or designs). Before the SMED method was implemented, the mold changeover took an average of 45 minutes and the following problems were observed: frequent assembly errors (e.g. imprecise mold fit), waiting for tools and lack of a work standard, as well as large time discrepancies between shifts. The SMED method was implemented at the selected station in the following stages:

1. Analysis of changeover activities. Cameras were used to assist, recording 3 changeover cycles. Changeover activities were divided into external and internal.
2. Separation of activities. As part of this stage, lubricants, release agents and socket wrenches were prepared in advance, and cleaning stages were moved outside the main station.
3. Conversion of internal activities to external activities. Quick-release holders were used instead of screws, and the mold change began to be performed by a 2-person team in parallel.
4. Improvement of activities (colour marking of matching elements and step-by-step instructions at the station).

As a result, the changeover time was shortened from 45 to 17 minutes, the availability of molds was increased, dimensional accuracy was improved thanks to better mold stabilization, and the number of assembly errors was reduced.

As part of the implementation of Lean Manufacturing tools in the analyzed enterprise, the Kaizen philosophy was also used to increase the frost resistance and durability of concrete raised garden beds by improving the mixing and dosing process of ingredients – in line with key customer requirements according to QFD. The implementation area was the concrete mixing and additive dosing zone – which particularly affects frost resistance and compressive strength. In this zone, before implementing the Kaizen philosophy elements, the following problems were found: variable consistency of the mix depending on the change, non-uniform share of additives increasing frost resistance and manual measurement of admixtures. As part of Kaizen activities, a weekly cycle of production team meetings was introduced, during which a joint analysis of quality control results took place, procedures were improved and operators were trained. As a result, the number of elements with low frost resistance decreased, fewer complaints were found and no additional tests were necessary upon receipt.

In order to assess the risk in the production process of concrete raised garden beds, an analysis was also carried out using the FMEA method. As part of this analysis, potential errors, their causes and effects were identified and priority numbers of severity, occurrence and detection were determined, and on this basis, a risk priority number was calculated. Preventive actions and actions for detectability were also indicated. The analysis covered all key production stages: preparation of molds, mixing of concrete, pouring, compaction, curing, demoulding and quality control (Table 1).

The highest Risk Priority Numbers (RPN) occur in the stages related to mold preparation and concrete mixing. Errors in cleaning and lubricating the molds lead to surface defects and dimensional non-conformities, while mix instability results in reduced strength and frost resistance. The curing stage also shows a high RPN, mainly due to the risk of microcracks, which can lead to complaints and shortened durability. A high RPN is also observed in the compaction/vibration stage – too short a vibration time leads to air bubbles and decreases the product's durability. Detectability actions focus on visual inspection, checklists, dosing automation, and time control – these are key elements in ensuring quality.

Table 1
FMEA method for the analysis of the concrete raised garden bed production process

Defect no.	Potential effects of defect	S	Potential defect	Potential causes of defect	Preventive actions	O	Detectability actions	D	RPN
Production stage: Mold preparation **Function/task:** Preparing clean and lubricated concrete molds									
1.	Uneven surface, concrete sticking	**6**	Dirty or unlubricated molds	Lack of cleaning/ lubrication procedure	Checklist, training	**7**	Visual inspection of mold condition before pouring	**6**	**252**
Production stage: Concrete mixing **Function/task:** Producing a homogeneous and recipe-compliant mix									
2.	Reduced strength, decreased frost resistance	**7**	Uneven distribution of additives	Manual dosing of admixtures	Automation of dosing	**6**	Electronic dispensers with dosing records	**6**	**252**
Production stage: Pouring into molds **Function/task:** Filling molds completely with concrete, no voids									
3.	Voids, mold non-conformity	**6**	Inadequate mold filling	Inadequate mix volume	Dosing volume control	**5**	Visual or weight verification of fill level	**5**	**150**
Production stage: Compaction/vibration **Function/task:** Removing air, increasing cohesion									
4.	Air bubbles, reduced durability	**8**	Inadequate compaction	Too short vibration time	Visual control	**4**	Surface observation, time monitoring	**6**	**192**
Production stage: Curing **Function/task:** Allowing concrete to achieve strength									
5.	Deformation, microcracks	**7**	Too early mold removal	Ruhing	Hardness control	**5**	Hardness measurement before demolding	**7**	**245**
Production stage: Demolding **Function/task:** Safe removal of element from mold without damage									
6.	Waste, complaints	**6**	Edge damage during demolding	Lack of auxiliary tools, inattention	Introduction of gripping tools	**5**	Edge inspection after demolding	**5**	**150**
Production stage: Quality control **Function/task:** Assessing product compliance with technical requirements									
7.	Non-compliant product delivered to customer	**9**	Defect not detected	Lack of training, inspection too fast	Training, control card with criteria	**4**	Random samples, checklist	**4**	**150**

SUMMARY

The work provides a comprehensive analysis of the design and optimization process for the production of concrete garden beds based on an integrated approach using the QFD method and Lean Manufacturing tools such as 5S, SMED, KAIZEN and FMEA method. The activities carried out were aimed at increasing the quality of the final product for the customer and streamlining the manufacturing process in a small company producing concrete products for construction. The research was conducted in a small plant, analyzing data collected from individual customers and distributors.

The work included detailed identification and classification of key customer requirements, assigning them appropriate technical parameters, and then assessing the interdependencies and importance of these parameters, using the QFD method. Thanks to the construction of the "House of Quality", it was possible to link customer requirements with specific technical parameters, which enabled targeted optimization. By implementing Lean tools, the company achieved many benefits. By implementing 5S Practices, the organization at the work station for forming and pouring concrete raised garden beds improved, and the number of non-compliant and defective products was reduced, thanks to order and standardization. The introduction of 5S practices also had a positive impact on the organizational culture and employee engagement. By implementing the SMED method at the steel mold exchange and cleaning station, the changeover time was shortened, which increased the availability of molds and production flexibility. The number of assembly errors was reduced and the workflow was improved, which reduced the unit cost of the product. Kaizen enabled the improvement of the quality of the concrete mix through the introduction of cyclical improvements, controls and training. The application of the FMEA method identified the most critical stages of the process, which require special attention. The greatest risks concern the technical parameters of the greatest importance to the customer (durability, frost resistance, aesthetics), which confirms the validity of the previous QFD analysis.

Implementation of QFD methodology and selected Lean tools shows that even small companies can effectively use world-class tools. It was shown that even such a simple product as a concrete raised garden bed can be optimized by considering the detailed needs of the customer and measurable technical parameters. As part of the improvement activities, the company should strengthen control over the most important parameters, optimize the composition of the concrete and introduce dimensional control tools to ensure high accuracy and stability.

The novelty of the work is the application of an integrated approach combining the QFD method and selected Lean Manufacturing tools (5S, SMED, Kaizen, FMEA) in a small enterprise producing concrete raised garden beds. So far, similar solutions have been described mainly in the context of large industrial plants - in the work, however, they were applied in the conditions of a small company with limited resources. A certain limitation of the work is the small research scale (one company and a limited sample of customers) and the lack of a stage of comparison with the competition, but it fills the gap between theory and practice in the context of SMEs from the construction and gardening industry.

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