

Preliminary design of an anthropomorphic cutting and potting system for automated agriculture

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Abstract. The study presented is part of the Rural Development Programme of the Tuscany Region and the European Union: the objectives are to limit the number of manual operations, to enhance technological transfer operations, to share best practices and to reduce the carbon footprint of the Scindapsus cuttings production chain. In this context, the work presents the approach to a preliminary design of an anthropomorphic system for automated cutting and potting of cuttings. For a better understanding of the current procedures and solutions, a critical analysis of the State of the Art of agricultural automation processes available in the literature was carried out. This study was developed in parallel with market research to identify the custom components to be produced to make a choice consistent with the technical specifications. The design has dealt with the system for handling and preparing the cuttings through panels and conveyor belts, starting from the needs defined in the initial phase. The analysis considered, both at a mechanical and functional level (evaluation of times and methods), the layout of production space with a high degree of automation for cutting and potting cuttings, with particular attention to the issues of the workplace safety and the maintainability of the elements: the best configuration of resources, personnel and equipment were designed through a *what-if* scenario analysis populated by deterministic and stochastic events.

1. Introduction

The Rural Development Programme of the Tuscany Region and the European Union is a project aimed to grant an optimal management of natural resources and climate action. This is possible by stimulating a balanced rural, social, and economic development, in order to create and maintain work opportunities, as stated in regulation 1305/2013 of the European Parliament and of the Council [1]. European Union has scheduled six main goals for an appropriate rural development, such as: to promote technological transfer and know-how to agricultural activities, enhance productiveness of existing rural companies, to preserve, promote and resume ecosystems related to agriculture and forestry.

This work is framed in this legislative, economic, and environmental context and is aimed to enhance technological transfer to reduce manual operations, to share best practices between companies and to reduce the carbon footprint of the Scindapsus cuttings production chain. Nowadays this process is totally provided manually by specialized workers. This work is intended to achieve a preliminary design and optimisation of an anthropomorphic cutting and potting system for automated agriculture to reduce processing times, increase productivity and reduce the cost of the final nursery product.

It is necessary to briefly analyse the State of Art of automation in agricultural processes. In the last decades and years robots and artificial intelligence are becoming more and more used in various

application fields, as they reduce risks related to dangerous operations. Originally, robots have been developed to replace humans by doing dangerous or dull operations [2], [3], but modern robot arms are widely used in every field: from heavy mechanical industries to agricultural applications. Agriculture, in fact, is regarded to be one of the most dangerous workplaces and it is mandatory to reduce the risk for workers: plenty of health problems have been identified, such as hearing loss, respiratory illnesses and different types of cancers [4], [5]. Manual operations such as pruning, harvesting, weeding, handling and digging include several risk factors such as awkward postures, iterative and prolonged trunk and knee bending and the carrying and lifting of heavy loads [[4], [6]].

Mechanisation in several operations has mitigated the aforementioned health problems, but it is necessary to develop new technologies in order to reduce environmental impact of agricultural processes and related mechanical risks [7].

Nowadays, in the era of Industry 4.0 [8], defined as “*the set of technologies, devices and processes [...] capable of operating in an integrated way along the several phases of the production process and along the several levels of the supply chain [...] that allow for self-sufficient production, integrated operations, decentralized decisions, minimum human intervention*” [9], [10], advanced robotics has been widely used and agricultural robots may represent a solution to this issue, but they should be in line with several technical requirements, such as: lightweight structure, small size and possibility to adapt to working area [11]. A mandatory technology for the application in agriculture field, characterized by a natural diversity that could not be eliminated from the final products, is the artificial vision. This field of research has grown very fast in last years especially with the application of Generative Adversarial Networks in recognize real life objects [12], in machine learning approaches [13] and generally speaking Artificial Intelligence [14]. Before introducing working methodology and the specific case study based on *Scindapsus* cuttings potting system, it is useful to focus on “sustainable development” definition, namely: “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” [11], [15]; this formulation has to be considered as a goal to achieve in every design application. Industry 4.0 can contribute positively to reduction of environmental impact of processes [9], but it can increase production of waste from electric and electronic equipment (WEEE [16]) and social problems [17] such as unemployment [18], even if the correlation between these two factors has to be studied deeply, due to higher production rate [19]. In parallel with applications, also sensors and automatic data collection for the Agriculture 4.0 is a promising field of research because supporting systems are mandatory to develop integrated technological solutions [20], [21], [22]. Authors from [23], [24] in addition propose a literature review to collect Agriculture 4.0 specific tools.

This work is intended to correlate every factor mentioned above to provide a preliminary layout design of an autonomous station for cutting, processing and potting *Scindapsus* cuttings in a high-automation degree process, nevertheless without forgetting social, logistic, economic, and environmental aspects related to this choice.

2. Case study: *Scindapsus* cutting production and potting

The FLO.ROBOT project is an opportunity to study and design a high-automation station for moving, cutting, and potting *Scindapsus* cuttings. A similar work but with a different plant application has been proposed by authors of [25], [26], [27].

As mentioned in the previous section, *Scindapsus*' production chain is now totally composed by specialized workers, thus the plant (see Figure 1) is moved and cut by hand. According to the manufacturer, this operation is characterized by a high level of repetitive operations and it is quite slow and time-consuming.

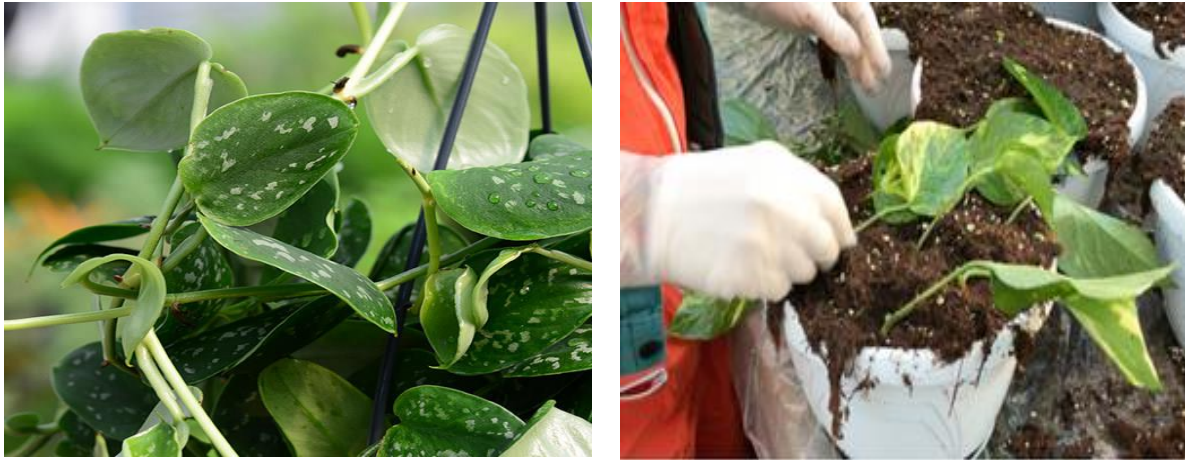


Figure 1: Left: Scindapsus potted and ready to be sold. Right: Scindapsus potted, manually by the worker.

Scindapsus is a flowering plant and it represents the core business of the manufacturer mentioned above. Its cultivation time varies from 12 to 36 weeks. This time includes four main phases:

1. Growing phase
2. Picking up the branch
3. Cuttings production
 - Every branch is cut into proper length
4. Potting phase

Cuttings' production (see Figure 2) is intended to be converted from a series of manual operation to a sequence of automatic ones. According to available data, idoneous branches have to be pick up manually and are characterized by widely variegated leaves and strong stem.

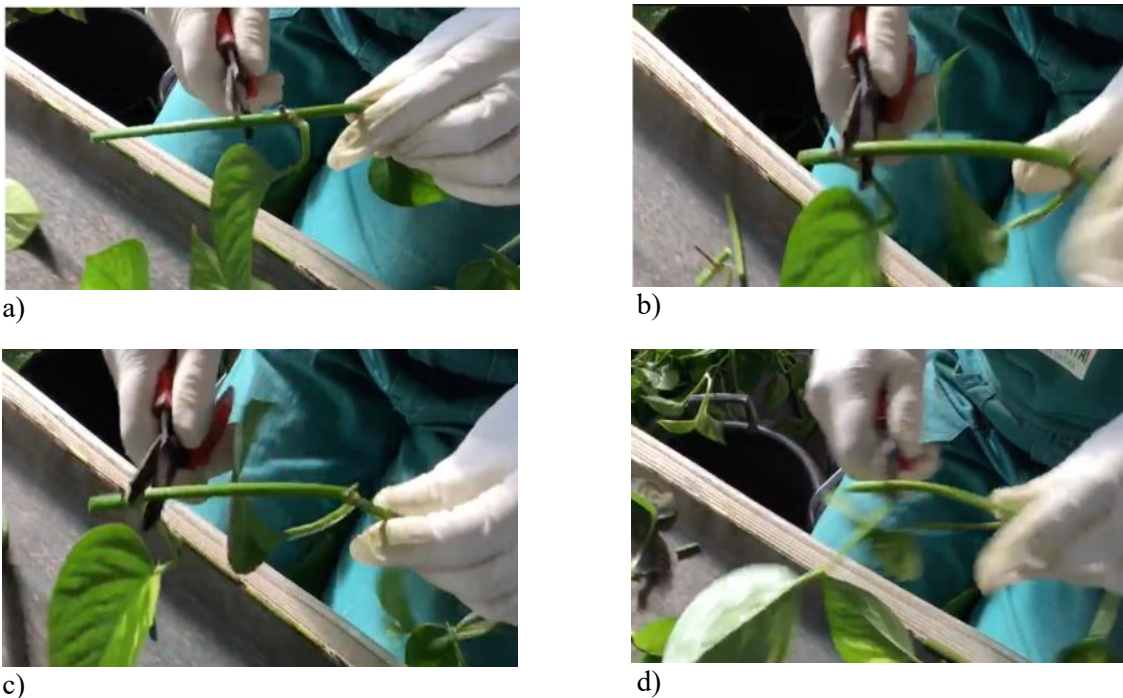


Figure 2. Operations needed to produce Scindapsus cuttings. a) A portion of stem is cut b) the branch is moved forward c) the first side cutting is obtained d) end of cuttings' production.

3. Design approach method

The motivation of the study relies on the relevance of such production for the manufacturing and nursery district including various companies in the area of Mount Amiata, near Siena, in the region of Tuscany (Italy), exporting worldwide. According to data and nursery prediction, the annual requirement of *Scindapsus* cuttings is 5,5 millions and this amount is estimated to become higher and higher.

The approach followed in the proposed activity is summarized in Figure 3. After a first phase of critical analysis of the State of the Art (see the the Introduction paragraph), a brainstorming is carried out to define the Customer Requirements (CRs) for the system. The CRs represented the input data for a QfD analys aimed to the definition of the Design Requirements (DRs) in terms of different alternatives from which to choose the best one according to the CRs and on which an environmental and economic assessment was also performed.

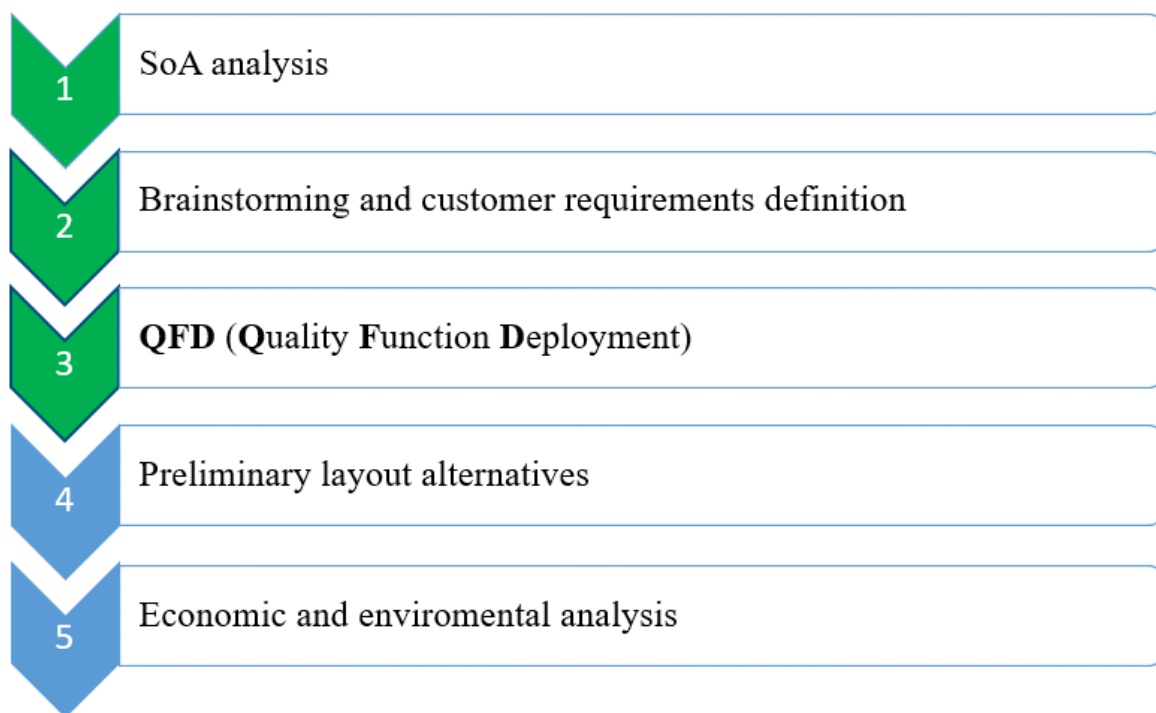


Figure 3. Design approach method.

3.1. *Quality Function Deployment*

As mentioned above, authors follow a structured approach Quality Function Deployment (QFD) based on to determine importance and correlation of the design parameters. In literature, this framework is largely used because of application easiness and of synthesis skills [28], [29], also when talking about environmental analysis [30]. An extract of the FLO.ROBOT QFD is shown in Figure 4 and it has been produced by the project stakeholders with the authors' support:

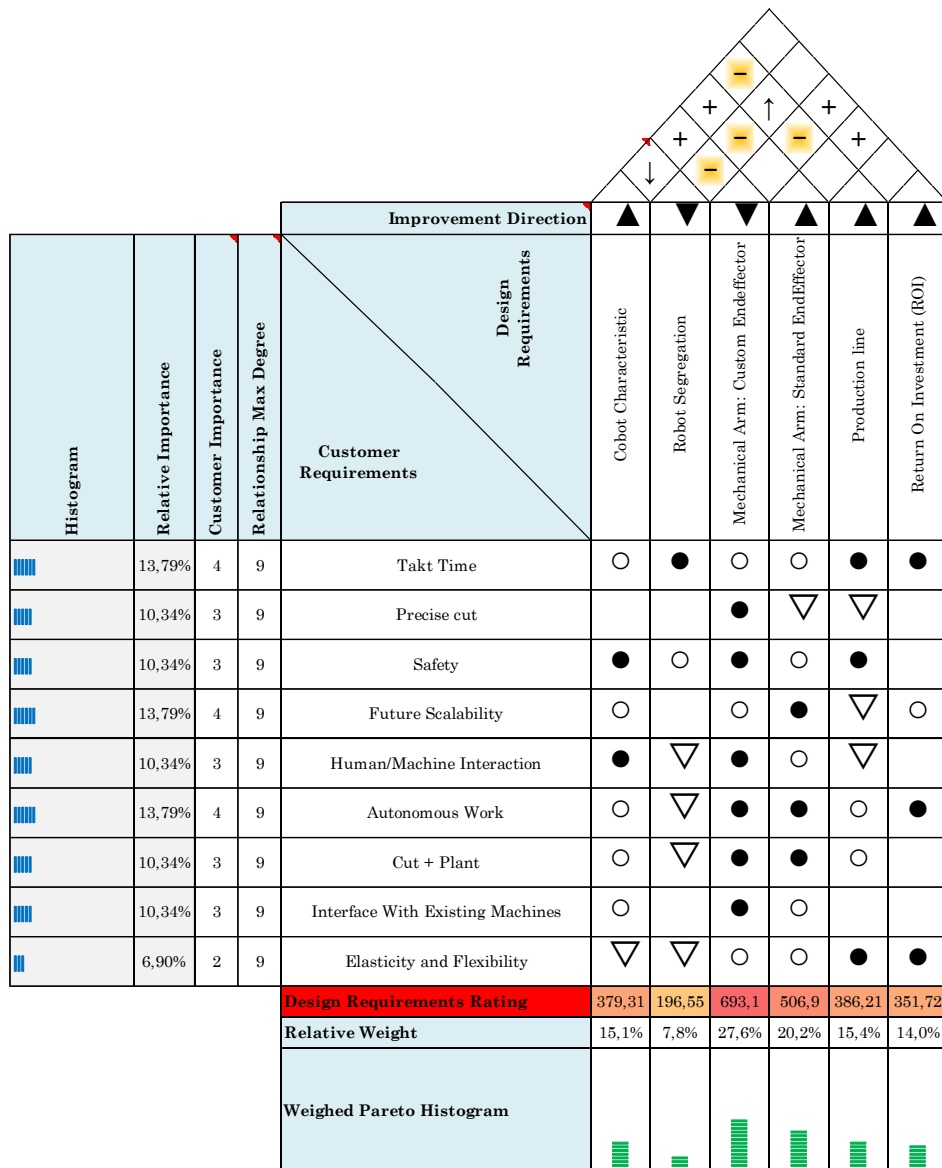


Figure 4. FLO.ROBOT QFD Application.

On the rows, the following “Customer Requirements” (CRs) have been identified:

1. Takt time: the system ability to not increase the total process takt time.
2. Precise cut: the system ability to precisely operate the cut.
3. Safety: mandatory to protect operator’s safety.
4. Future scalability: the possibility to future upgrade the system.
5. Human/machine interaction: the machine operational easiness for the operators.
6. Autonomous work: the system ability to be fully operative without the operator supervision (excluding loading and unloading phases).
7. Cut and plant: the plant cutting and positioning in the pot (final product) machine ability.
8. Interface with the existing machines: system ability to be implemented in the existing job floor.

9. Elasticity and flexibility: system ability to positively react to plant changes and volume changes respectively.

On the basis of the CRs above, the following Critical to Quality parameters (CTQs) and “Design requirements” (DRs) have been defined:

1. Cobot characteristics: this means the possibility to develop a part of the machine close to a cobot, so able to share the same working areas with human operators and without barriers that could slow down the working activity.
2. Robot segregation: some parts could be dangerous for the operators and so must be not accessible to them. For this reason, a precise definition of the system layout has to be developed according to essential health and safety requirements of 2006/42/EC on Machines safety.
3. Mechanical arm_custom end-effector: a possible macro-solution to be evaluated is the design of an anthropomorphic arm equipped with an end-effector characterized by a larger work flexibility despite a larger initial cost.
4. Mechanical arm_standard end-effector: the exact opposite of the previous solution, this one provides a minor work flexibility with a minor initial cost. In addition, the hardware/software interface between all the system components could be harder to develop with a non-controllable factor as a standard end-effector.
5. Production line: this characteristic refers to the possibility to integrate the final product within the existing production line in order not to increase the total takt time or to create additional process bottlenecks.
6. Return on Investment (ROI): finally, this parameter refers to the customer need to implement a machine able to decrease the total cost of ownership of the entire process.

The solution of an anthropomorphic arm equipped with a custom end-effector results the most interesting one between the other possibilities because provides the highest rating among the DRs. This value comes from the “Coupling factor” between DRs and CRs multiplied with the “Customer Importance” vector.

The symbols in fact mean a strong correlation with a dark point, a moderate correlation with a light point and a weak correlation with the light triangle: in numbers, a value of 9, 3 and 1 has been respectively assigned. A second winning point is the high score reached in “Interface with Existing Machines”: in fact, the job floor is already equipped with many existing production automation tools (a machine to put earth in the pot, semi-automatic material handling, final product packaging, ...) and a project constraint was to reuse most of the existing tools.

In the QFD “roof”, the cross-correlation matrix between the DRs, authors determine that the “Machine Segregation” could help improve the productivity, but the loss in flexibility and so in future development of this application let the designer to choose a more “cobot-like” solution.

The “QFD roof” in fact is filled with a upward arrow in case of strong positive correlation, a downward arrow in case of strong negative correlation, a “+” symbol in case of positive correlation and a “-“ symbol in case of negative correlation. There is also some graphical information in the histogram columns defined in the left and in the matrix bottom part: those graphical approach simply resume the numerical results in order to make the study more affordable for everyone working on this project.

In conclusion, the QFD framework provides a structured approach for the designers to determine not only the best possible solution among all the available but also provides a different “problem glance” to increase the system features.

The outcomes of QFD analysis allow defining the following technical specifications functional to the identification of the different layouts and related system’s components.

In Table 1 the data related to the technical specification of the robot are summarized.

Table 1. Cobot's technical specification.

Technical specification	Range
Range of operation	700-2000 mm
Manipulation time	< 2 s
Cost	< 50000 €
After-sale service	Available
Get custom end-effector	Available

3.2. Preliminary layout alternatives

According to QFD results and technical specification three layouts have been analysed to evaluate integrability with the existing production line. In this paragraph authors will expose and discuss solutions according to project stakeholders and technical requirements.

Two mechanical layouts require a panel where the operator has to hang up *Scindapsus* branches and a properly designed u-shaped duct, shown in Figure 5 in order to let the cobot move the branch.

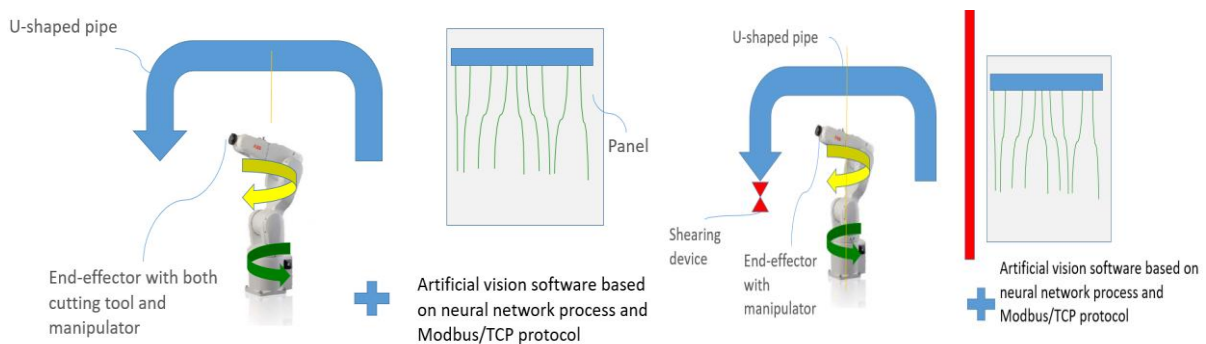


Figure 5. Schematic mechanical layouts with two solutions: 1) end-effector with both cutting tool and manipulator, 2) shearing device at the end of the pipe.

These solutions differ from each other as in the first one the cobot end-effector has to drag and cut the cuttings, while in the second layout the cutting operation is demanded to a shearing device, placed at the end of the duct. Due to the production volume, this kind of solution is not functional and may not grant working volumes required from the project stakeholders. The u-shaped duct is realized using a pipe with a radial access to enable the end-effector grab and move the *Scindapsus* leaves and make them assume a proper position to the stem; but this would require two or more cobots to keep present working volume: in fact, using only one mechanical arm, transporting operation would unacceptably reduce productivity of the station.

Another solution is shown in in Figure 6 and Figure 7. Branches are properly fixed by the worker to a custom belt conveyor with elastic band sewn on it and moved by a traction pulley and a stepper motor; cutting and grabbing functions are demanded the cobot's end-effector.

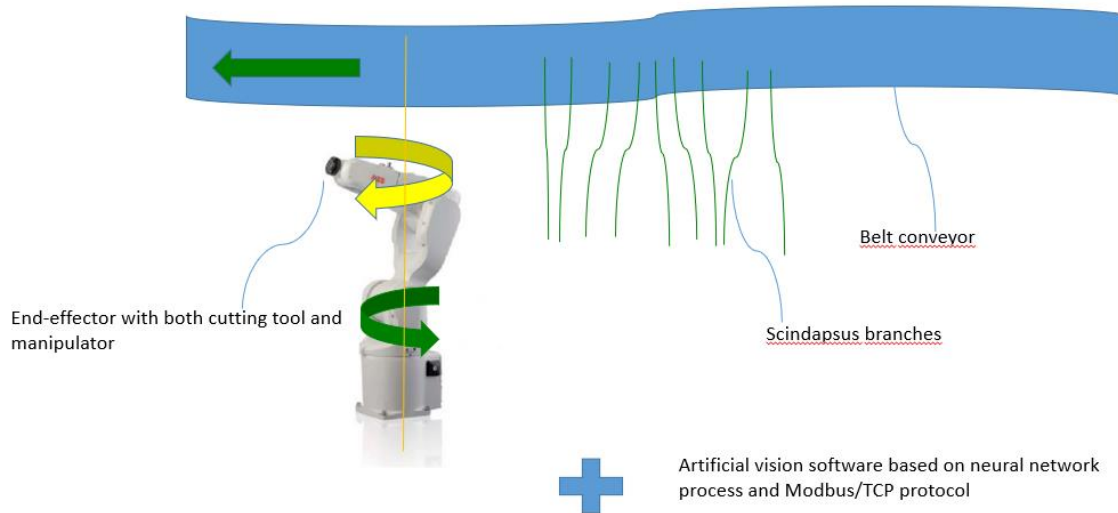


Figure 6. Schematic mechanical layout with belt conveyor.

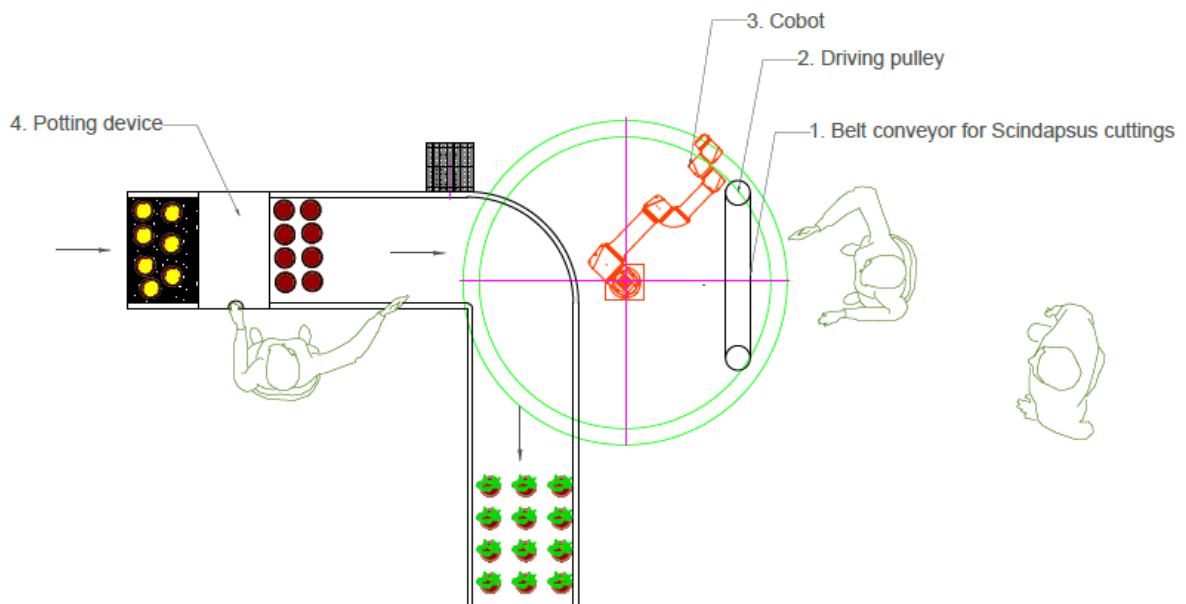


Figure 7. Mechanical layout with belt conveyor and potting device.

This solution has been analysed in further details as it respects following requirements:

- *Serviceability.* Properly formed workers can maintenance the system;
- *Future scalability.* The system presented in Figure 7 can be modified using an higher number of pulleys in order to hang more branches
- *Good integration with the existing production plant*

3.3. Economic/Environmental impact analysis

One of the “Customer Needs” is the ROI generation of the system. It means that the machine must be economically sustainable for the company and so the revenues coming from implementation must be greater than the sum of implementation and operational costs, the total cost of ownership in other term.

That is the reason why authors developed a process model to investigate the mutual interdependencies between the entire system cost drivers. The used environment is a “Discrete Events Process Simulator”, a kind of sandbox where all the atom operations and resources are putted together with their mutual interaction and statistical characterization to develop Montecarlo simulation to study the system long term behaviour.

Discrete event simulation is a well-known approach to the process design to experiment different solutions in a numerical environment, so advantages are mostly in rapidity and cheapness of the attempts. In agricultural, instead, is commonly used in logistic and transportation problems [31], [32] where production issues are not very well investigated. The application presented in this paper is referred to a greenhouse production that is closer to an industrial process, this is the reason why the authors decided to implement the discrete event simulation. Next step is to determine the statistical characterization of time and cost of each atom activity.

The BPMN standard [33] has been chosen because of its easiness of process representation and because it is a largely used standard in process analysis application. The standard models the “ring of application” as a “swimming pool” where the “lanes” are the single process owners. In Figure 8, the BPMN-like model is shown:

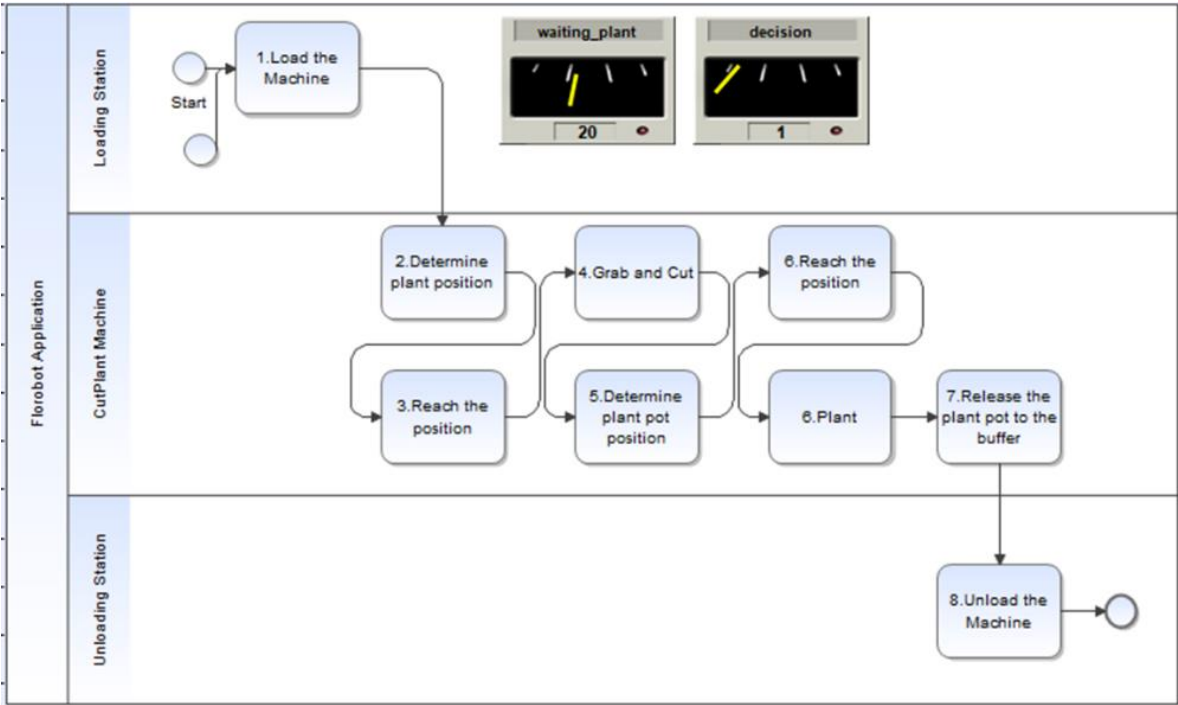


Figure 8. Process BPMN diagram.

In this model the swimming pool has been chosen as the “FLO.ROBOT Application”, where the stakeholders are the mechanical system (“CutPlant Machine” in the central lane), the place where the operator loads the machine with the Scindapsus to be cut (“Loading Station” in the upper lane) and the place where the final pots are unloaded to be sent to following activities (“Unloading Station” in the lower lane). Each lane is equipped with a resource, one operator in the loading station, one operator in the unloading station and the FLO.ROBOT machine in the central lane. In Figure 9 the FLO.ROBOT resource characterization interface is given as an example:

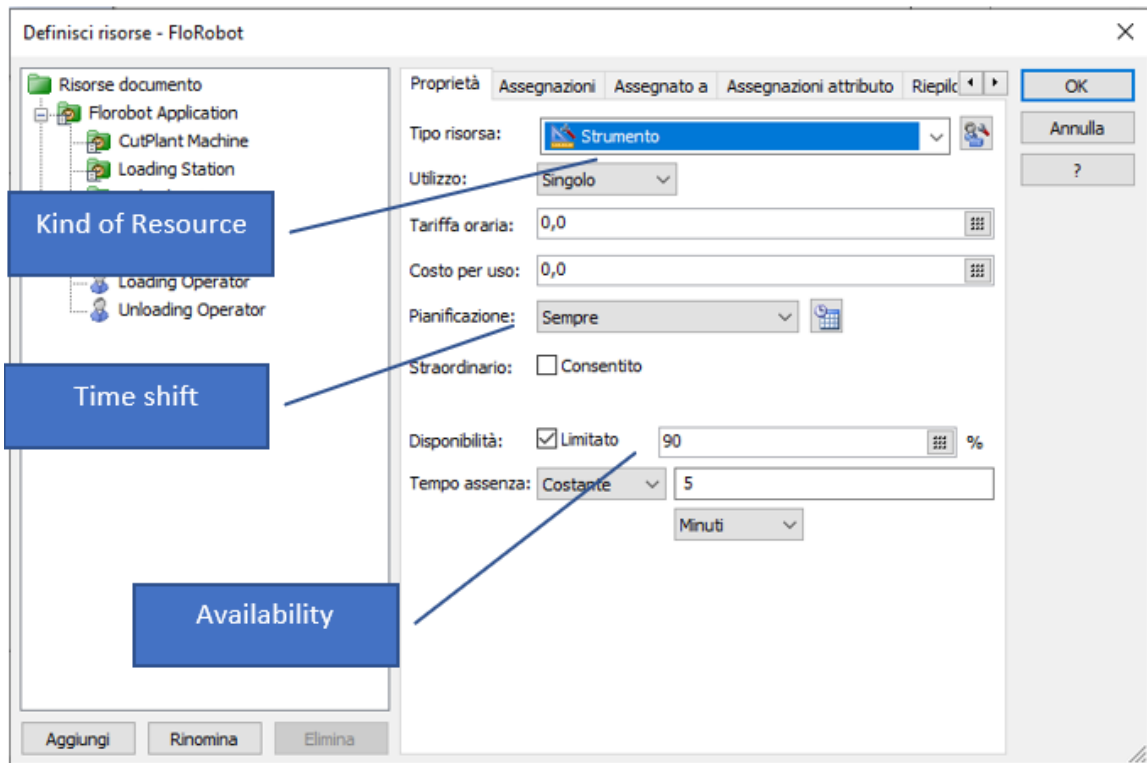


Figure 9. Resource characterization interface.

The graphical interface shows that it is possible to set up the hour cost for utilization and the cost per use of the resource. They are set at “0” because this parameter will be calculated in the final balance. In the central window part, the software allows defining the resource time planning, in other words the working days shifts where it is available: FLO.ROBOT machine is of course always available in any day or night time. Lastly, in the lower part of the windows, the Process Simulator interface allows determining the system availability such as total working time net of faults. The example given shows that the FLO.ROBOT application is 90% of time available and 10% occupied with set-ups, repairs, regulations, etc. The characterization has been developed for the “Operator” resources, too. It is important to highlight that time and costs parameters have been inferred by the data sheet information and by expert opinions collected during technical meetings. In fact, it will be possible to be more efficient with the statistical characterization when a system prototype will be realized and will be available for measurements. However, the aim of this preliminary design is to develop a design framework and to investigate different process design alternatives.

Each box in the “swimming pool” represents an atom activity in which the process has been divided, and more in details:

1. *Load the machine*: in this activity an operator set up the plants in the transportation belt to make them available for cutting process.
2. *Determine plant position*: in this activity the artificial vision system determines the position of the Scindapsus knot between the leave and the stem and communicate coordinates to the anthropomorphic arm controller.
3. *Reach the position*: this activity models the behaviour of the anthropomorphic arm when it moves from the zero position to the cutting area.
4. *Grab and cut*: in this activity the anthropomorphic arm grab the leaves under the cutting knot and then makes the cut.

5. *Determine plant pot position*: this is the activity where the artificial vision system find out the position of the plant pot and communicates the coordinates to the anthropomorphic arm controller.
6. *Reach the position*: the anthropomorphic arm moving from cutting position to the planting position.
7. *Plant*: the activity of planting a Scindapsus.
8. *Unload the machine*: in this step a second operator takes the filled pots away from the output conveyor belt and addresses them to the following activities, out of the scope of this project.

The model has been also provided with two counters that help the process analyst to debug the model before to use it. They measure the value of a supporting variable and the total number of waiting plants within the flow.

Once created the process map, the statistical characterization of each activity must be done. The software application allows adding many parameters and statistical distribution to synthesize the activity behavior. As it is possible to see from Figure 10, each activity has a graphical interface form to add these values:

Figure 10. Activity characterization form.

As an example, the “3. Reach the position” form is shown. It is possible to see in the first text box the “NormDist(6,5;1)” that represent the statistical distribution the software will use in the Montecarlo simulation shown next in this paper. More in details, the software will use a Normal distribution with average 6,5 and standard deviation 1 seconds to determine the time needed by the anthropomorphic arm to reach the position to cut the Scindapsus. This form has been filled up for all the activity represented in the model with the data reported in Table 2:

Table 2. Statistical characterization parameters

Activity	Statistical distribution (s)
1. Load the machine	Triangle(5;15;8)
2. Determine plant position	Norm(2;0,1)
3. Reach the position	Norm(5;1)
4. Grab and cut	Norm(17;4)
5. Determine plant, pot position	Norm(2;0,1)
6. Reach the position	Norm(5;1)
7. Plant	Norm(13;1)
8. Release the plant pot to the buffer	3
9. Unload the machine	Triangle(5;15;8)

There are two further considerations to do:

1. As previously described, these numbers come from a data sheet analysis and from interviews with the work group. To be more precise it is mandatory to make a data collection campaign on the prototype to validate the model.
2. The used distributions are the normal one and the triangular. Normal has been used for tools activities where the triangular has been use for activities that involve human operator. It is only a commonly used heuristic in the process modeling when data are not enough to determine the correct statistical distribution.

Once all the parameters have been set up, the Montecarlo simulation reports the average performance of the system as reported in Table 3 here below. The simulation time has been set up for 5 working weeks with a one shift working period (08.00 AM - 05.00 PM), 5 working days per week for the operators. Results are reported in minutes:

Table 3. Simulation results

Lane	Number of transactions	Cycle Avg	Work Avg	Waiting Avg
CutPlant Machine	2234	101,79	0,91	77,52
Loading Station	2234	290,76	0,16	1,68
Unloading Station	2234	169,64	0,15	0,42

The columns represent:

1. *Lane*: the system department.
2. *Number of transactions*: it represents the total amount of pots the system produced in the simulation period.
3. *Cycle Avg*: the average time a single plant pot needs to be completely produced. This time includes also waiting for available resources and when outside the working period.
4. *Work Avg*: the average time the pots spent being worked. This time does not include any waiting time.
5. *Waiting time*: the time each pot spends in waiting an available resource. This time does not include the time spent waiting in not working shifts.

This configuration has been considered as a base line to determine how sensible the final result is to any variation in these data. For this reason, authors developed a series of Montecarlo simulations changing the average values in the activities data input form. Results are presented in Table 4 here below and in Figure 11 the data interpolation:

Table 4. Sensitivity analysis results

Variation	Number of transactions	Delta production
-20% Baseline	2980	+746
-10% Baseline	2488	+274
Baseline	2234	0
+10% Baseline	1993	-241
+20% Baseline	1990	-244
+30 % Baseline	1982	-256

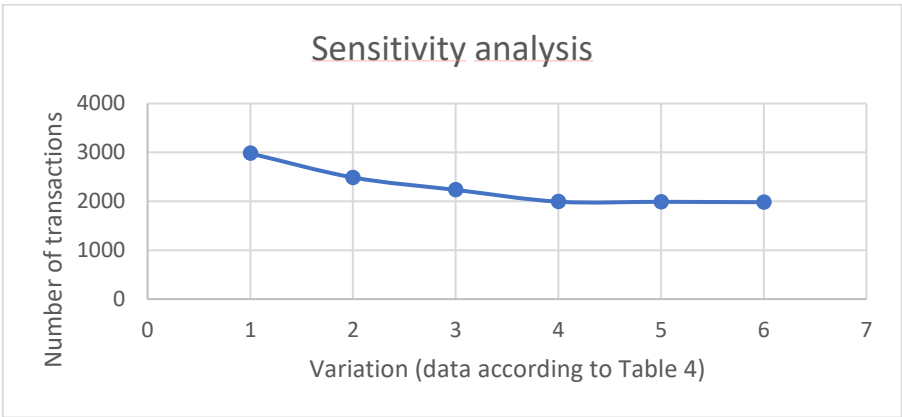


Figure 11. Sensitivity analysis results

It is clearly visible that the production converges to a value in this range of variation. It means that it is not necessary in this domain to increase the machine performance: in fact the system will give similar performances with an extra expenditure increase. In addition, from Table 3 it is possible to see that the Waiting Average is a low parameter value for the Loading Station and for the Unloading Station. This means that the two operators are poorly saturated and so their efficiency is low. For this reason, authors proposal is to use only one operator to load and to unload the machine to keep lower the total cost of ownership. Simulation results with only one operator are reported in Table 5.

Table 5. Single operator sensitivity analysis

	Variation	Number of transactions	Delta production
1	-20% Baseline	2961	+727
2	-10% Baseline	2488	+254
3	Baseline	2234	0
4	+10% Baseline	1993	-241
5	+20% Baseline	1990	-244
6	+30 % Baseline	1982	-252

Results prove that only one operator is enough to work with the FLO.ROBOT system. Savings of this results are quantifiable in one “Full Time Equivalent” (FTA) cost for the organization.

For this proposed solution a cost analysis has provided, both both from economic and environmental point of view. The data needed for this analysis are:

1. Hour cost for electric energy: authors used the average cost for a kWh in Italy that is quantifiable in 0,10691 €/kWh.
2. Power absorbed by the robotic arm: authors determined this data starting from data sheets values. The used number is 0,39 kW.
3. Carbon intensity: the average equivalent carbon dioxide released in the atmosphere. This value has been set at 255 gCO₂eq/kWh as proposed by EEA, European Environmental Agency [34].

The three scenarios simulation and analysis are reported in Table 6:

Table 6. Environmental and economic analysis simulation results

Variation	Delta Production	Cost (€)	Delta Cost	Equivalent Carbon dioxide (gCO ₂ eq)	Delta Equivalent Carbon Dioxide
-10% Baseline	+254	1,22€	+0,30€	2598,03	+239,31
Baseline	0	0,92€	0	2358,71	0
+10% Baseline	-241	0,82€	-0,1€	2082,78	-275,93

The results show that the best solution with chosen layout and initial assumptions is the -10% Baseline with only one operator working on the system. Again, this result comes from the time and cost assumptions made at the beginning of this paper: once the project will be finished and the prototype ready, the presented framework will be used again with more realistic data.

4. Conclusion and final remarks

In conclusion, in this paper the authors propose a structured approach to a preliminary design of an anthropomorphic cutting and potting system for automated agriculture. The Scindapsus cutting and planting operation represent a case study characterized by a product natural variability and by a limited literature in agriculture automation field. This application needs a neural network for visual recognition and an anthropomorphic arm for handling and therefore the support of a structured approach will help the system design.

The authors firstly studied Customer Requirements and Design Requirements through the Quality Function Deployment approach to prioritize the solution to be implemented: this point has been extremely important because the working team was opened to many persons and so this tool helped to focus ideas and proposal.

As a result, a set of alternatives has been identified and a concept design of each one has been made to investigate pros and cons. The most viable solution resulted an anthropomorphic arm with a custom end-effector.

The proposed activity includes also an economic and environmental analysis based on a discrete event simulation approach to determine the best process parameter level.

In the case study, the authors have evaluated the minimal number of operators to be involved in the process and the machine speed that reduces the carbon footprint despite the lowest reduction of productivity.

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References

- [1] Regulation n. 1305/2013 2013 *Regulation no. 1305/2013 of the European Parliament and of the Council* (EAFRD)
- [2] Zhang B, Xie Y, Zhou J, Wang K and Zhang Z 2020 State-of-the-art robotic grippers, grasping and control strategies, as well as their applications in agricultural robots: a review *Computers and Electronics in Agriculture* **177** p 105694
- [3] Tai K, El-Sayed AR, Shahriari M, Biglarbegian M and Mahmud S 2016 State of the art robotic grippers and applications *Robotics* **11**
- [4] Benos L, Bechar A and Bochtis D 2020 Safety and ergonomics in human-robot interactive agricultural operations *Biosystems Engineering* **200** pp 55-72
- [5] Kirkhorn SR and Schenker MB 2002 Current health effects of agricultural work: respiratory disease, cancer, reproductive effects, musculoskeletal injuries, and pesticide-related illnesses *Journal of Agricultural Safety and Health* **8** p 199
- [6] Benos L, Tsaopoulos D and Bochtis D 2020 A Review on ergonomics in agriculture. Part II: mechanized operations *Applied Sciences* **10** p 3484
- [7] Bochtis D D, Sørensen C G, Busato P and Berruto R 2013 Benefits from optimal route planning based on B-patterns *Biosystems Engineering* **115** pp 389-395
- [8] Braña FJ 2019 A fourth industrial revolution? Digital transformation, labor and work organization: a view from Spain *Journal of Industrial and Business Economics* **46** pp 415-430
- [9] Beltrami M, Orzes G, Sarkis J and Sartor M 2021 Industry 4.0 and sustainability: towards conceptualization and theory *Journal of Cleaner Production* p 127733
- [10] Castelo-Branco I, Cruz-Jesus F and Oliveira T 2019 Assessing Industry 4.0 readiness in manufacturing: evidence for the European Union *Computers in Industry* **107** pp 22-32
- [11] Moysiadis V, Tsolakis N, Katikaridis D, Sørensen CG, Pearson S and Bochtis D 2020 Mobile robotics in agricultural operations: a narrative review on planning aspects *Applied Sciences* **10** p 3453
- [12] Galteri L, Ferrari C, Lisanti G, Berretti S and Del Bimbo 2019 A Deep 3D morphable model refinement via progressive growing of conditional Generative Adversarial Networks *Computer Vision and Image Understanding* **185** pp 31-42
- [13] Swain M, Singh R, Thakur AK and Gehlot A 2020 A machine learning approach of data mining in agriculture 4.0 *Int. J. Emerg. Technol* **11** pp 257-262
- [14] Jha K, Doshi A, Patel P and Shah M 2019 A comprehensive review on automation in agriculture using artificial intelligence *Artificial Intelligence in Agriculture* **2** pp 1-12
- [15] Imperatives S 1987 Report of the World Commission on environment and development: our common future *Accessed Feb* **10** pp 1-300
- [16] EC 2012 *Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment 2012 (WEEE)*
- [17] Rose DC and Chilvers J 2018 Agriculture 4.0: broadening responsible innovation in an era of smart farming *Frontiers in Sustainable Food Systems* **2** p 87
- [18] Kurt R 2019 Industry 4.0 in terms of industrial relations and its impacts on labour life *Procedia computer science* **158** pp 590-601
- [19] WEF 2016 *Future of Jobs Report: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution, Global Challenge Insight Report*
- [20] Symeonaki E, Arvanitis K and Piromalis D 2020 A context-aware middleware cloud approach for integrating precision farming facilities into the IoT toward agriculture 4.0 *Applied Sciences* **10** p 813
- [21] Puranik V, Ranjan A and Kumari A 2019 Automation in agriculture and IoT *4th International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU)* pp 1-6

- [22] Pisanu T, Garau S, Ortu P, Schirru L and Maccio C 2020 Prototype of a low-cost electronic platform for real time greenhouse environment monitoring: an agriculture 4.0 perspective *Electronics* **9** p 726
- [23] Zhai Z, Martínez JF, Beltran V and Martínez NL 2020 Decision support systems for agriculture 4.0: survey and challenges *Computers and Electronics in Agriculture* **170** pp 105-256
- [24] Klerkx L, Jakku E and Labarthe P 2019 A review of social science on digital agriculture, smart farming and agriculture 4.0: new contributions and a future research agenda *NJAS-Wageningen Journal of Life Sciences* **90** pp 100-315
- [25] Huang YJ and Lee FF 2010 An automatic machine vision-guided grasping system for *Phalaenopsis* tissue culture plantlets *Computers and Electronics in Agriculture* **70** pp 42-51
- [26] Jin X, Li D, Ma H, Ji J, Zhao K and Pang J 2018 Development of single row automatic transplanting device for potted vegetable seedlings *International Journal of Agricultural and Biological Engineering* **11** pp 67-75
- [27] Choudhary R, Rajarathnam M, Alekya M, Hari KP and Kumar SS 2020 Agriculture automation system *Journal of Physics: Conference Series* **1706**
- [28] Leary M and Burvill C 2007 Enhancing the quality function deployment conceptual design tool *Journal of Mechanical design* p 129
- [29] Vanegas LV and Labib AW 2001 A fuzzy quality function deployment (FQFD) model for deriving optimum targets *International Journal of Production Research* n. 39 **1** pp 99–120
- [30] Yüksel H. 2010 Design of automobile engines for remanufacture with quality function deployment *International Journal of Sustainable Engineering* 3 **3** pp 170–80
- [31] Nilsson D 2001 Discrete event simulation as a performance analysis tool in agricultural logistics systems *IFAC Proceedings* **34** pp 19-24
- [32] Turner A, Sama M, McNeill S, Dvorak J, Mark T and Montross M 2019 A discrete event simulation model for analysis of farm scale grain transportation systems *Computers and Electronics in Agriculture* **167** p 105040
- [33] Business process notation and modelling <http://www.omg.org/spec/BPMN/2.0>.
- [34] https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-8#tab-googlechartid_googlechartid_googlechartid_googlechartid_chart_11111.