ISTEA
ITALIAN SOCIETY OF SCIENCE, TECHNOLOGY
ENGINEERING OF ARCHITECTURE

Re-shaping the construction industry

A cura di

Angelo Ciribini

Giuseppe Alaimo

Pietro Capone

Bruno Daniotti

Guido Dell'Osso

Maurizio Nicolella

MAGGIOLI EDITORE

ISBN 978-88-916-2486-4

Maggioli Editore è un marchio di Maggioli S.p.A.
Azienda con sistema qualità certificato ISO 9001:2008
47822 Santarcangelo di Romagna (RN) • Via del Carpino, 8
Tel. 0541/628111 • Fax 0541/622595

www.maggiolieditore.it

e-mail: clienti.editore@maggioli.it

Agosto 2017

"A digitized design process to optimize workspaces allocation in industrial buildings of medium-sized companies"

Vito Getuli*, Federico Tramonti, Tommaso Giusti*, Pietro Capone*

**University of Florence, Florence, Italy*

Dipartimento di Ingegneria Civile e Ambientale DICEA

vito.getuli@unifi.it, federico.tramonti@gmail.com, tommaso.giusti@unifi.it, pietro.capone@unifi.it

Topic: BIM-Automated Model, Facility Layout Problem, Optimization, Force-Directed Graph drawing Algorithm.

Abstract

The contribution aims to develop a computational and digitalized design process, in order to re-engineer production layouts in terms of allocation of working machines, in medium and small manufacturing companies. The process leads consequential steps from the analysis of the facility layout till the material and worker handling systems, with particular reference to their spatial allocation within the plant area of the host building. The data collected are subsequently stored in a Building Information Model which acts as "input driver" for the design process in order to reach a local replanting of workspaces, given a number of building constraints. By using a BIM-interoperable approach which includes a Space Syntax Analysis, the result is a redesigned parametric-model with optimizes machines' allocation of the addressed case study. The design process has been validated in three different companies and suggests a different allocation of workspaces compared to their original spatial placement.

1. Introduction

Modern industry is experiencing a very competitive era, and increasingly complex methods are being adopted to optimize production times, improve product quality, and reduce production costs to maximize profits. A *facility layout* is defined as the arrangement of everything needed for the raw material transformation into finished products destined for sale, and *optimizing* means finding the best arrangement of physical facilities to provide efficient operations (Hassan e Hogg, 1991). A good approach to *Facility Layout Problem* (FLP) could have significant impact on the productivity level and it can be reduce up to 50% of the total operating coast (Xie and Sahinidis, 2008).

The proposed paper fits into a wider project which aims to develop design workflows within BIM Environments for planning, optimizing and simulating the temporal space allocation of workspaces within construction site first and then in manufacturing systems (Getuli et all, 2016). The proposed application seeks to improve internal logistics for a company involved in processing of metal laminates. The adopted procedure analyses the relations between facilities (e.g., machines, material handling system) according to the production logics by using a visual monitoring and reaches the *optimal layout distribution* (constraint-based) by using an algorithm (P. Nourian, 2013) which operates according to the classic theory of graphs.

2. Background and literature

There are several approaches in literature which have treat the problem of facility layout. The goal, in any optimization plant layout, is principally to minimize material flow costs by positioning cells or equipment in designated position that will result in the reduction of materials or parts trasportation distances, as typical example of wich was accomplished in the design of a plant layout using Computerized Relative Allocation of Facilities Technique (CRAFT) (Prasad et all, 2014). Genetic algorithm-based solutions are proposed in (Enea et all, 2005) that respond to the changes to the product design, mix and volume in a continuosly evolving work environment. A higher level heuristic solution, based on a concept “Tabu Search”, a mixed non-linear programming model, is presentated in (Arostengui et all, 2006). (Kanduc et all, 2016), using force-directed graph drawing methods (also called spring embedders), are one of the most commonly used methods to represent graph visually.

3. Methodology and instruments description

The proposed *Design Workflow*, within a BIM Environment, consists of three phases: (**1**) **Data collection**; information such as the Plant Layout Design, Production Flow Charts, Safety Procedures, Working Procedures, workspaces shapes and dimensions are stored by using visual monitoring and interviews with workers. A predefined

spreadsheet able to store all the required information needed for the analysis is used. (**2**) **Information Model (IM) creation**; which includes the aforementioned Production Data is automatically generated by using a generative algorithm of families of 3D parametric objects developed in *Dynamo* (a visual programming extension for Autodesk® Revit to manipulate data and automate processes).
(**3**) **Research of the Optimal Layout Distribution**. The optimal allocation of machines, given their mutual adjacency ratio and boundary conditions imposed by the building (structural elements, entrances and exits, escape design), is reached by using a "*Space Syntax Analysis*" algorithm (P. Nourian, 2013) in a graphical algorithm editing environment (*Grasshopper*).

Care is taken to achieve technological (tools) and logical interoperability (information flow), across the steps of the suggested design process. The operational workflow and the supported tools are shown in Figure 1.

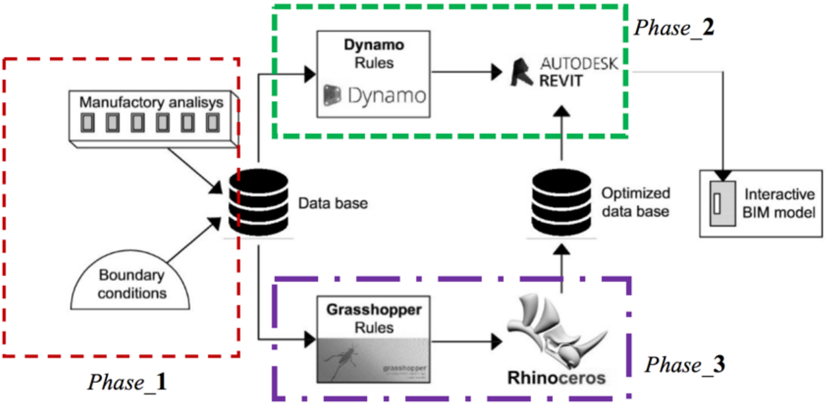

Fig. 1 – *Operational Workflow*

Phase 1

At this phase, the existing production layout of the company involved in processing of metal laminates, which is used as first test case, has been analysed. The Data Collection involved gathering of the following information:

(1) Machine allocation, shapes, dimensions and boundary conditions in terms of proximity with other machines
(2) Operational workflow
(3) Machine adjacent relationships
(4) Flow paths
(5) Boundary conditions (constraints) depending on the building structure

The data collected are stored in a spreadsheet according to common parameters, as depicted in Figure 2. Each machine is discretized by using two rules: (a) machines' shapes are considered as rectangular blocks, (b) the total volume is the sum of machinery area, support space, maintenance area, and space for furnishings (Figure 2).

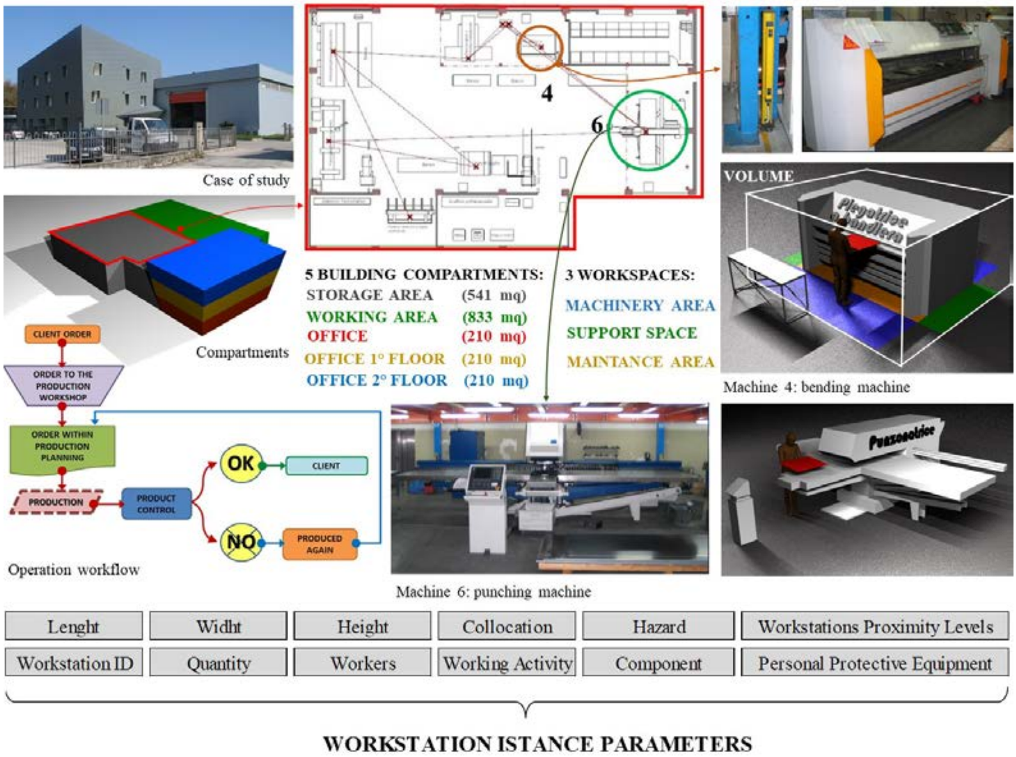

Fig. 2 – Data collection of the production process and building constraints

Phase 2

The data acquired under Phase 1 allow the generation of the three-dimensional parametric objects, which reproduce the building elements and the workstations. Usually, the creation of parametric objects -the so-called *Component Families*- is a manual operation; nevertheless, this process has been automated and customised by using *Dynamo*, a dedicated tool for processing graphic algorithms within a BIM modelling environment (Figure 3). The proposed algorithm works as a bridge between the database and the parametric objects and automate the generation of the host elements to which the parameters will be associated. As the first step, the collected data is read by the database (Figure 3, Step 1) and the algorithm processes the machine-size parameters (*Length*, *Width*, *Height*) and creates an *In-Place Element*, as many times as indicated by the "*Quantity*" parameter indicating the number of detected workstations (Figure 4).

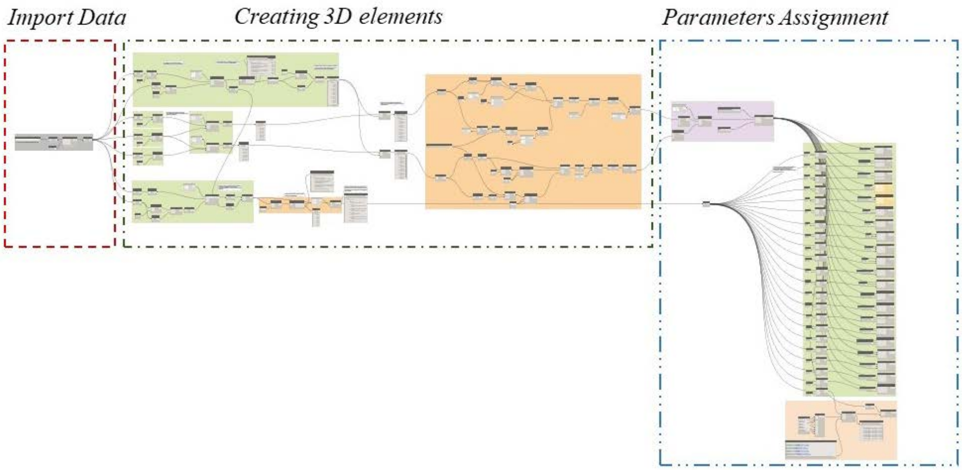

Fig. 3 – Dynamo algorithm to automatically model workstations

By using this capability, the Workstation Instance Parameters in Figure 2 are attached to the *Component Family*, here called “Machine”, and a number of machines are generated as *In-Place Elements* belonging to the same masterclass, through a two-way, dynamic and updateable match. So that means that the user/designer can change each parameter or value, included in the spreadsheet, obtaining an immediate update of the Information Model. At this level, the elements are placed in a generic position within the modelling environment, in accordance with the compilation order of the database. This approach allows us to rapidly reproduce the working environment of the given company and store the data by using a predefined framework able to work as a Common Data Environment. Due to the research objects, a low Level of Detail (LOD) has been used to represents the workstations as opposed to a high Level of Information (LOI) able to describe the performance requirements of each components (Figure 4).

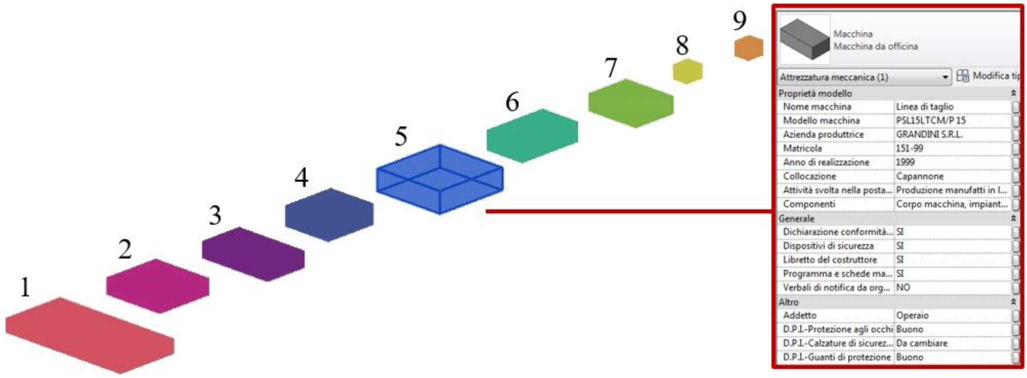

Fig. 4 – In-Place Elements for workstations and corresponding information requirements

Phase 3

At this level, the object is to rearrange the workstations allocation in order to reach the optimal distribution according to the detected proximity levels. In this regard, adjacent study has been integrated and customized in the proposed workflow by using *Space Syntax* (P. Nourian 2003), an algorithm in *Grasshopper* Modelling Environment (Figure 5) which draws an interactive bubble diagram in terms of plan layout graphs.

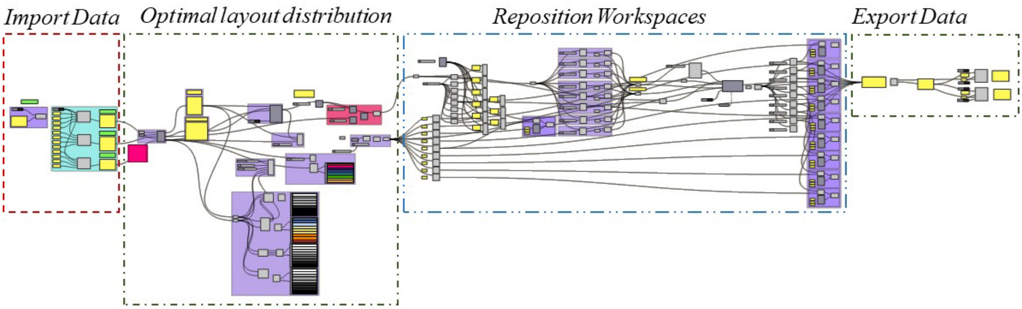

Fig. 5 – Grasshopper algorithm for Space Syntax Analysis

In the CAD environment, tied to the algorithm in Figure 5, a number of points, which correspond to the geometrical position of the gravity centre of each workstation, are drawn and subsequently connected in accordance with the data of production process by using straight line which correspond to a proximity level assigned by the user (Figure 6).

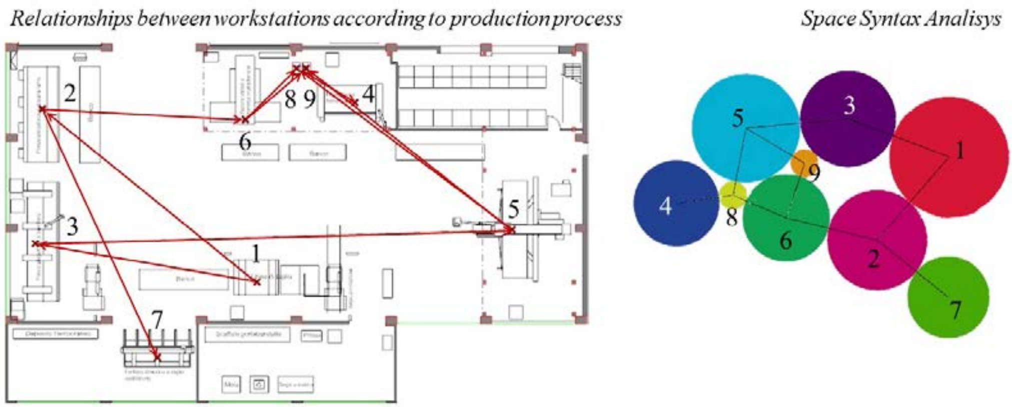

Fig. 6 – Collected (left) and optimal (right) connectivity pattern

The tool produces a connectivity pattern, that still has an abstract meaning, and each workstation are conceptually idealized as a sphere, has shown at the right of the Figure 6. A unique topological incorporating that model on an plane is generated.

The algorithm (Figure 5) works by a set of attractive and repulsive forces acting recursively on graph vertices, seeks a 'relax' situation for a graph, and reaches to a graph drawing which depicts the optimal workstation allocations according to the imposed constrains. In the customized algorithm, attractive forces stand for workstations proximity levels and repulsive forces stand for building constraints (e.g., columns, walls, building's entry and exit).

According to the aformentioned logics, the first arrangement is abstract and not contextual with the building. By using the relative coordinates [x,y] of the optimized configuration, the obtained bubble diagram is adapted and contextualized within the production site. Through a physical simulation tool (*Kangaroo*), which reproduces the boundary conditions in terms of attractive and repulsive forces, the bubbles are reallocated into the defined domain as depicted at the right of the Figure 7. This domain is obtained from the boundary conditions of the case study, such as structural mesh, internal paths, entry and exit of the production site. Once again, the bubble position in the domain is automated through a proximity function. The output of the simulation is shown in Figure 7, where it is possible to note the different allocations of some workstations.

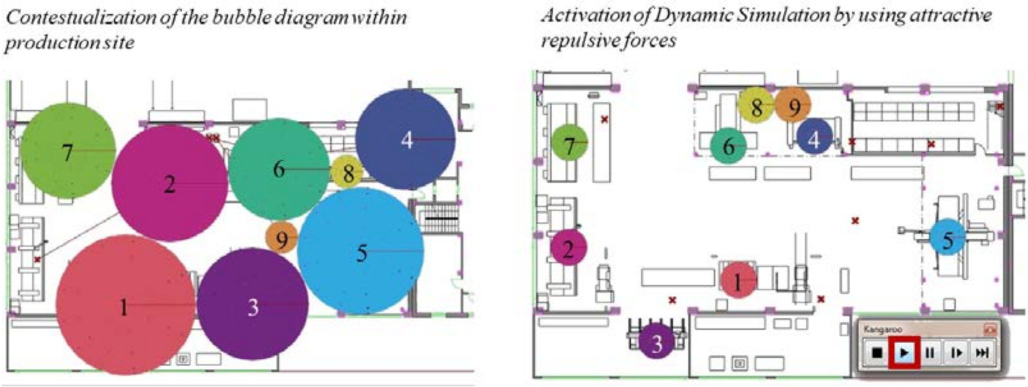

Fig 7. Contextualization of the bubble diagram (left), and optimal workspaces allocation based on the building constraints (right)

In order to align the Production Information Model (PIM) with the optimal workspaces configuration, the algorithm exports the workstation's coordinates [x,y] in the initial database. By doing so, the parametric workstations generated in Phase 2 and visualized in Figure 4 are automatically repositioned in the BIM modelling environment, as it is possible to visualize in Figure 8.

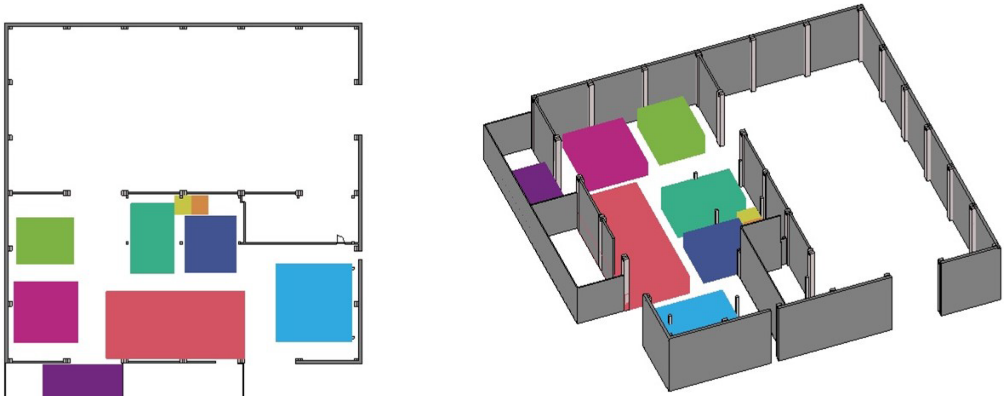

Fig. 8 – Production Information Model (PIM)

4. Conclusions

The paper defines a design workflow to optimize the production layout in medium size factories and to produce an optimized BIM, here called Production Information Model (PIM), which should work as a Common Data Environment (CDE) for constant updating of the information about the production process looking for Health and Safety Management. The result obtained shows (Figure 9) as three of the nine workstations occupy a different position.

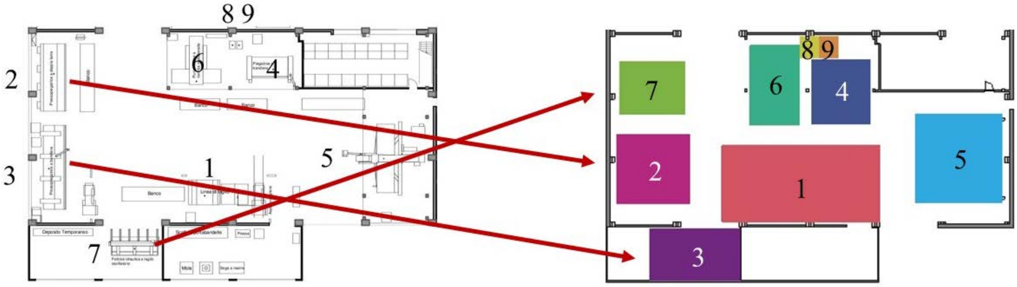

Fig. 9 – Comparison between the detected and proposed configuration

By doing so, the manufacturing process can effectively be improved simply decrease the movement times at some of workstation, without intervening on the casing architectural. The proposed method could be used by designer, during the planning phase, as a support tool to find the best workspaces configuration when building and architectural constraints exist; during the management phase it is used to have a valid tool to store information through a constantly updated Data Warehouse.

5. Acknowledgment

The authors would like to mention and acknowledge Ruta S.r.l in the person of Dott. Paolo Ruta for providing the case study to test the real effect of the proposed workflow.

6. References

[1] Getuli V., Peretoli G., Sorbi T., Kindinis A., Capone P. (2016), ISTEA Back to 4.0: rethinking the digital construction industry, Maggioli Editore.

[2] Enea, M., Galante G., and Panascia E., "The facility layout problem approached using a fuzzy model and a genetic search" Journal of Intelligent Manufacturing, pp. 303-306, (2005).

[3] Prasad, N. H., Rajyalakshmi, G. and Reddy, S. A., "A Typical Manufacturing Plant Layout Design Using CRAFT Algorithm", Procedia Engineering,1808-1814, Elsevier , (2014).

[4] Kanduc T., Rodic B., "Optimization of Machine Layout Using a Force Generated Graph Algorithm and Simulated Annealing", Int j simul model 15, pp. 275-287, (2016).

[5] Arostegui M., Kadipasaoglu S., Khumawala B., "An Empirical Comparison of Tabu Search, Simulated Annealing, and Genetic Algorithms for Facilites Location Problem", Springerlink International Journal of Production Economics, pp. 742-754, (2006).

[6] Nourian P., Rezvani S., Sariyildiz S., "A configurative approach to architectural layout, proposing a computational methodology", Spatial Performance and Space Syntax, pp 357-365, (2013)

[7] Sanjeev B. Naik, Dr. Shrinkant Kallurkar, "A Literature Review on Efficient Plant Layout Design", Internal Journal of Industrial Engineering Research and Development, Vol VII, pp 43-51, (Aug. 2016).

[8] Pinto Wilsten J., Shayan E., "Layout Design of a Furniture Production Line Using Formal Methods", Journal of Industrial and Systems Engineering Vol.I pp 81-96, (Spring 2007).

[9] Jia Zhenyuan, Lu Xiaohong, Wang Wei, Jia Defeng, Wang Lijun, "Design and Implementation of Lean Facility Layout System of a Product Line", Internal Journal of Industrial Engineering, pp. 260-269, (2011).