LOCATION ORIENTATION MANIPULATOR BY KONRAD WACHSMANN, JOHN BOLLINGER AND XAVIER MENDOZA

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Abstract :

1969 one of the first 7 dof kinematics was designed by Konrad Wachsmann and his Team, John Bollinger and Xavier Mendoza. Except of some exhibitions within the seventies, in which this project was described shortly, the Motion Machine or Location Orientation Manipulator remained nearly thoroughly unknown. This article will present one of the very first Manipulators which should be a prototype for architectural assembly assignments and systems and which should lead to further research on an empirical basement. Concerning construction assignments, Konrad Wachsmann and his Team realized the gap of the automated assembly systems as mission critical for the introduction of totally industrialized and automated building systems. This approach is a sign of a highly valuable view of the interdependencies between the production and assembly systems and the building systems and concepts. This kind of holistic approach concerning the technical and technological needs and requirements of the construction, production and assembly systems, is currently well known as Robot Oriented Design (Bock, Thomas, 2010). So, Konrad Wachsmann and his team took some basic developments of the following 40 years in advance, which makes it worth to have a closer look at the project called Location Orientation Manipulator.

The gap of the automated assembly process

10 Years after publishing his famous Book, Turning Points in Construction, the prototype of a kinematic is completed. This mechanical prototype, which allowed the free orientation of an object in space on highly flexible way, anticipated many developments of later robotic projects. The following described Project called LOM (Location Orientation Manipulator) was an attempt of Wachsmann, to erase the by then rarely considered weakness of the assembly process of the industrialized construction systems.

„Indem also eine allgemein zusammenhängende Ordnungstheorie des Produzierens, Fügens und Verbindens vorausgesetzt werden muss, die Anspruch und Harmonievorstellung beeinflusst, kann erst in ihr sich der schöpferische Akt zur vollen Wirkung entfalten.“ (Wachsmann, 1959)

At this point Konrad Wachsmann, John Bollinger and Xavier Mendoza wanted to start with their research, to attain the same range of industrial production for architectural construction projects, as it was already state of the art for other sectors of industries at the beginning seventies. (Lauer, 2009) The following article will give a short introduction into the thoughts that led to the development of the LOM, and the project itself.

Background of the Motion Study Machine: the Dissertation at the USC

John Bollinger and Xavier Mendoza developed concepts at Konrad Wachsmann attendance, which finally led to the deployment of a prototypic machine and its final version. The project was financially supported by the Weyerhäuser Foundation. The efforts for the planned project were legitimated as follows:

Xavier Mendoza, January 8, 1969

In view that industrialized buildings ought to be products which are assembled from other products, industrially mass- produced, and that the erection of buildings ought to consist of the assembly of these products, whether partially at the factory or subsite or fully at the final erection site (if indeed final site still exists in spite of this meaning of building), then the material handling device, the positioning and assembly mechanism becomes of utmost importance.

I propose the following:

1. The study of materials handling devices and of positioning and assembly mechanics.

2. In order to determine principles of motion, mechanics, and precision.

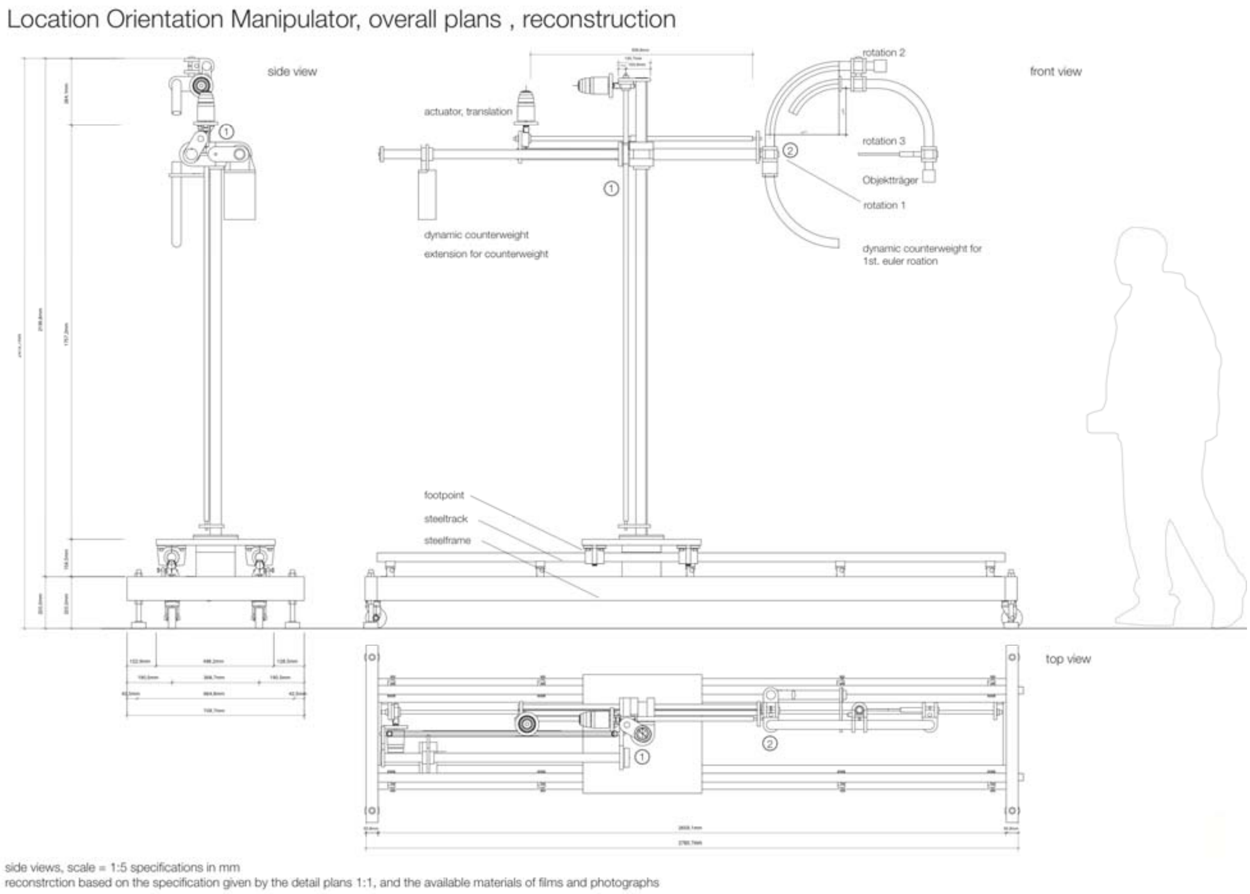
3. And further, to propose applications of similar devices to industrialized building, and further developments of such devices. (Mendoza, 1969)

The Motion Study Machine

The Location Orientation Manipulator was made to be a systematical device, which should enable to perform studies for coordination of objects in time and space, concerning the applications for industrialized buildings. (Teamstudy, 1969) [1] The physical simulation by the Motion Study Machine for recording and controlling various types of motion, in the light of the technology used at that time, formed the only way to collect reliable data, and to bring this knowledge into order for further developments. Comparable modes of operation can be identified in todays robotics as motion modelling. (Maier, 1989)

Therewith the machine LOM has been designed for the empirical research of the phenomena of time, space and geometry, as well as its recording and activation for tangible applications. (Maier, 1989) [2] „The LOM is unique among existing manipulators both in its physical configuration and in its application to the study of kinematics of assembly processes in building.“ (Mendoza, 1961)

Fig. 1: The plans show the Overall geometry of the LOM, reconstruction of the author



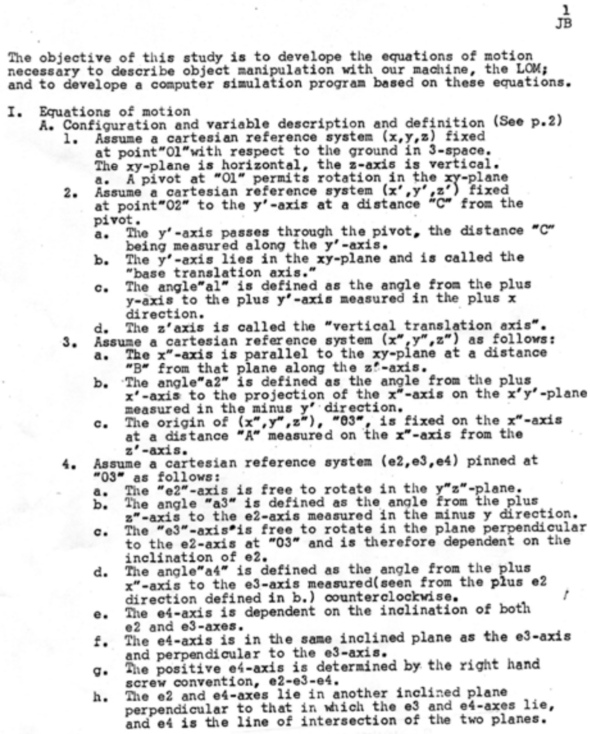
Sequenciation and Multiplication: the collection of empirical data.

The development of this project has been executed so far, that a mathematical model for the description of the motions of the LOM, as well as the arrangement of a test- assembly program was made available.

At the particular articulated connection elements, the coordinates defining an object in space could be measured precisely, and probably adjusted by the aid of the mathematical calculations. Through these calculations and the physical recording of the resulting trajectories, the movements of the LOM were fixed. Later on, the characteristic trajectories necessesary for the assembly of several abstract construction elements were recorded in order to be able to repeat these movements several times with the same grade of precision.

„A set of assembly process concepts and a mathematical model of the LOM, derived from kinematic studies used in the design of the LOM, provide a fundamental reference of variables of assembly.“ (Mendoza, 1971)

Fig.2: Excerpt of the mathematical model by John Bollinger, KWA, Berlin



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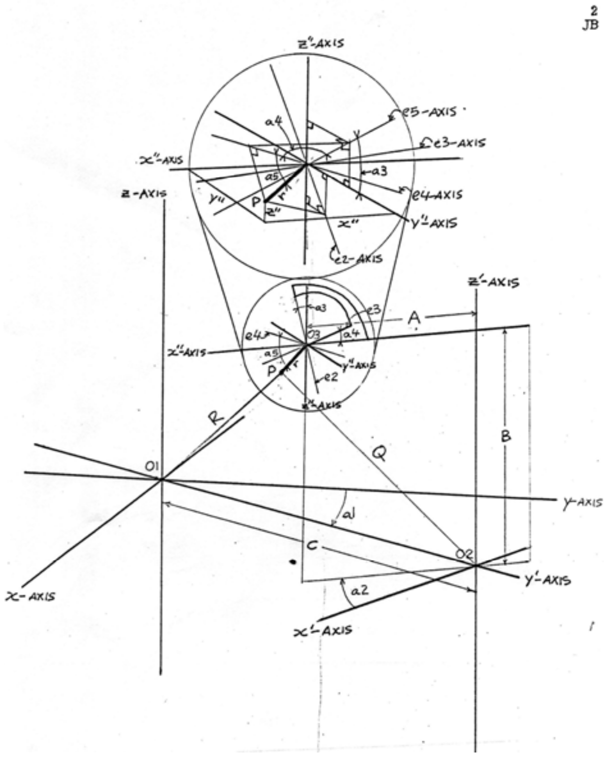
The objective of this study is to develope the equations of motion necessary to describe object manipulation with our machine, the LOM; and to develope a computer simulation program based on these equations.

I. Equations of motion
   A. Configuration and variable description and definition (See p.2)
      1. Assume a cartesian reference system (x,y,z) fixed at point"O1"with respect to the ground in 3-space. The xy-plane is horizontal, the z-axis is vertical.
         a. A pivot at "O1" permits rotation in the xy-plane
      2. Assume a cartesian reference system (x',y',z') fixed at point"O2" to the y'-axis at a distance "C" from the pivot.
         a. The y'-axis passes through the pivot, the distance "C" being measured along the y'-axis.
         b. The y'-axis lies in the xy-plane and is called the "base translation axis."
         c. The angle"a1" is defined as the angle from the plus y-axis to the plus y'-axis measured in the plus x direction.
         d. The z'axis is called the "vertical translation axis".
      3. Assume a cartesian reference system (x",y",z") as follows:
         a. The x"-axis is parallel to the xy-plane at a distance "B" from that plane along the z'-axis.
         b. The angle"a2" is defined as the angle from the plus x'-axis to the projection of the x"-axis on the x'y'-plane measured in the minus y' direction.
         c. The origin of (x",y",z"), "O3", is fixed on the x"-axis at a distance "A" measured on the x"-axis from the z'-axis.
      4. Assume a cartesian reference system (e2,e3,e4) pinned at "O3" as follows:
         a. The "e2"-axis is free to rotate in the y"z"-plane.
         b. The angle "a3" is defined as the angle from the plus z"-axis to the e2-axis measured in the minus y direction.
         c. The "e3"-axis is free to rotate in the plane perpendicular to the e2-axis at "O3" and is therefore dependent on the inclination of e2.
         d. The angle"a4" is defined as the angle from the plus x"-axis to the e3-axis measured(seen from the plus e2 direction defined in b.) counterclockwise.
         e. The e4-axis is dependent on the inclination of both e2 and e3-axes.
         f. The e4-axis is in the same inclined plane as the e3-axis and perpendicular to the e3-axis.
         g. The positive e4-axis is determined by the right hand screw convention, e2-e3-e4.
         h. The e2 and e4-axes lie in another inclined plane perpendicular to that in which the e3 and e4-axes lie, and e4 is the line of intersection of the two planes.



For example, the sequence of certain movements permitted the insertion of diagonals into the six outside surfaces of a tetrahedron.

„This program combines a number of paths and strategies, which enable the transformation of elements from the matrix into the inscribed tetrahedron state, and which demonstrate the versatility of the LOM.“ (Mendoza, 1971)

Afterwards, the improvements gained by the physical simulation, were transformed into a more sophisticated mathematical model. This is already a matter of iterative methodology towards an approach of the best possible solution, as it is currently used in many computer programs to solve complex assignments.

The hypothetical assembly program is evaluated and improved by physical simulation of the process with the LOM. “ (Mendoza, 1971)

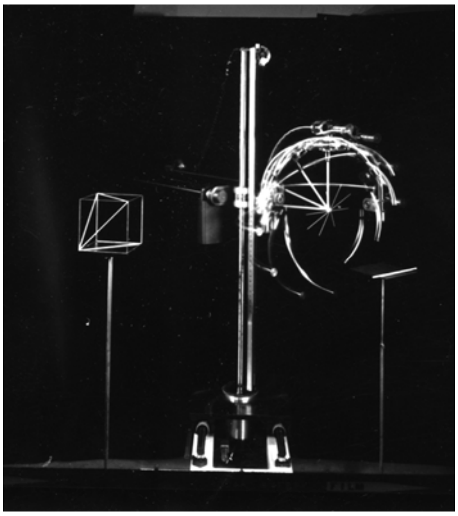
Therefore it is possible that, in a comparably early period of time, this research should form a basement for a totally industrialized and automated building technology. (Lauer, 2009)

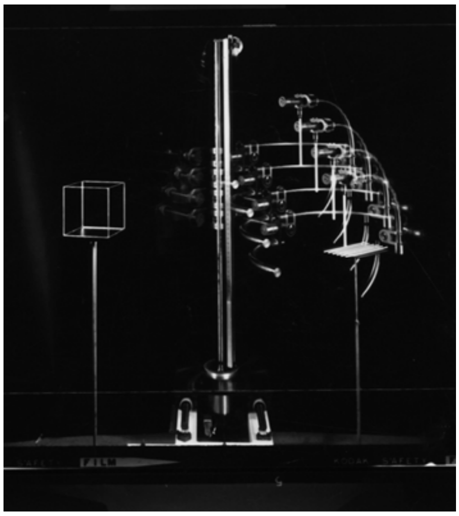
Similarly to that, it is finally formulated 1971 at the end of the research and the dissertation concerning the purpose of the performed studies. The value is mainly recognized in the collection of totally new empirical data in face of the problems and requirements of a totally new industrialized building. Moreover, it should help to sort out the best solutions from an according spectrum for multiple fields of applications, by the help of empirical analysis.

„This dissertation supports the need for physical experimentation and simulation in solving problems of building system assembly, where theory is incomplete and where strategic decisions among many alternatives are best made empirically.“ (Mendoza, 1971)

That the LOM was designed exactly for this broad field of application can also be proven by the fact, that shortly after the completion of the project, a manufacturer for lights wished to buy the device from the USC, for light testing. (Konrad Wachsmann Archive, 1972) It should not be overseen that its use was planned for material and sound testing. "…to show the variety of tensions within the test piece due to its orientation in reference to the gravity, for light as well as for acoustic research, which means sound wave analysis. (Maier, 1989)

Fig.3/4: Sequenciation of the assembly of simple geometry, KWA, Berlin





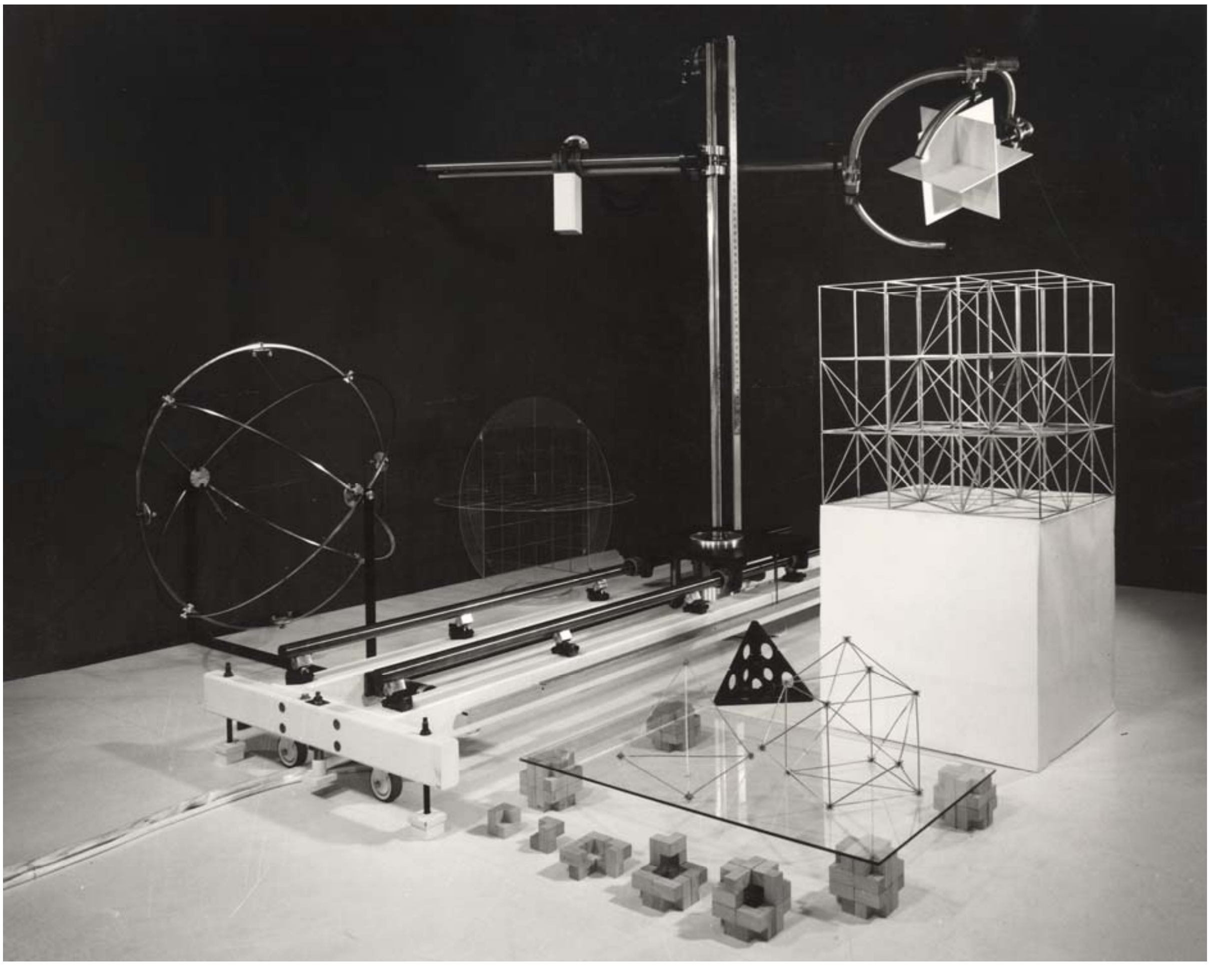
Geometry of the LOM: Arrangement of the geometric characteristics

The geometry of the LOM can be separated into three conceptual divisions:

Crosspoints which enable the rotation around one axis, Crosspoints which enable the translation parallel to one axis, and the connection beams between these crosspoints. Thereby it must be confined, that this is only valid, if the rotation is performed around the objects point of balance. All other kinds of rotations have also an effect on the objects location, as in case of a rotation of an object around a point or axis, which is not its point of balance, a distance is driven. The specific arrangement of translations and rotations of the Location Orientation Manipulator has been designed for the sake of this correlation. This means, that it was tried to collocate the crosspoints in order to determine the geometric orientation of an object separately from its location. More precisely, the geometry of the LOM is able to manipulate an object in its orientation without moving it out of its point of balance, or to perform complicated countermovements of further crosspoints. (Lauer, 2009) Similar to that, the position of an Object can be manipulated, without changing its orientation. This clear and intended separation is distinctive for the geometrical design of the LOM, as it shows the relation between positioning and orientation of an object within the 3 dimensional space, in a clear and intuitive manner. "The LOM separates the functions of translation and rotation and facilitates the process of visualization and mathematical description" (Maier, 1989)

The LOM seems to be optimized in view to a maximized field of application in the future. (Lauer, 2009)

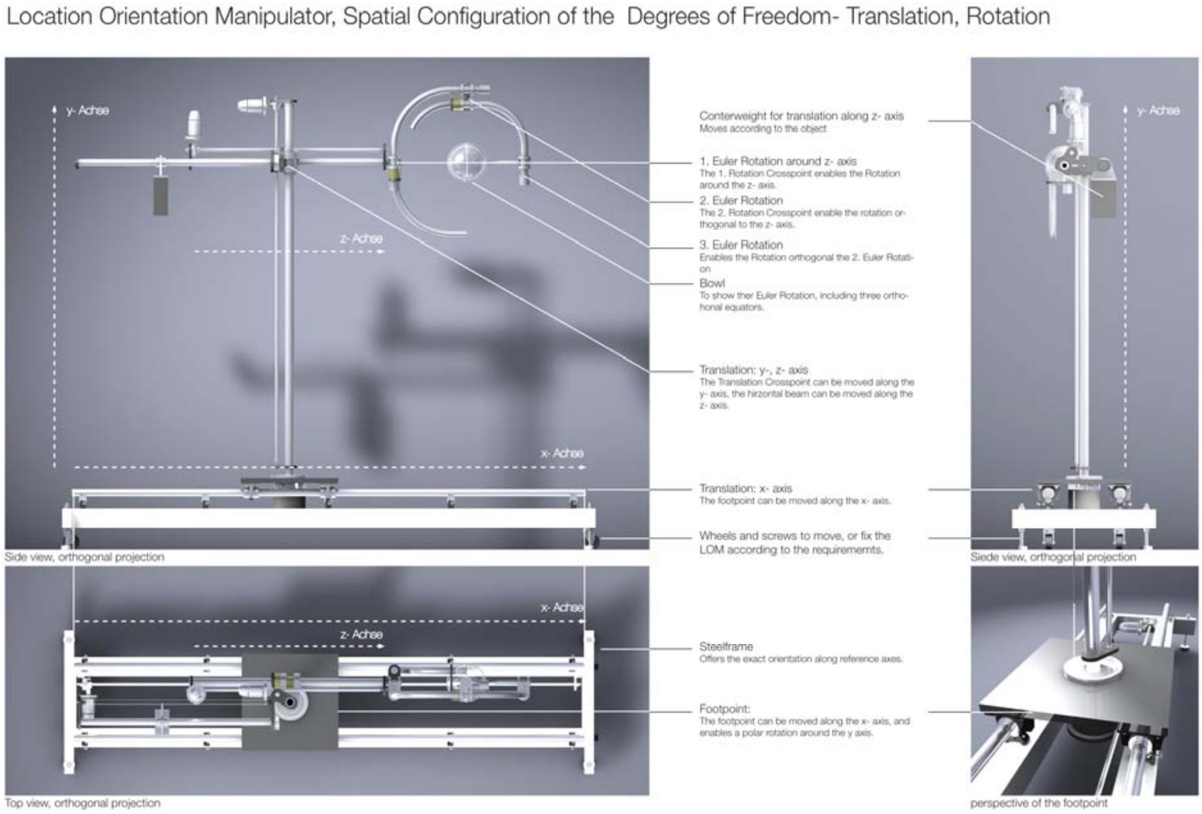
Fig.5: Geometrical Tests, KWA, Berlin



Configuration of the degrees of freedom

All in all, the LOM is designed with seven degrees of freedom. Three translations to position an object in three spatial dimensions, three euler rotations realized by a sod of cardanic suspension and one polar rotation at the basepoint. This polar rotation is actually a redundant degree of freedom, but it enhances the flexibility of the LOM configuration and enables to reach around obstacles. The use of one redundant degree of freedom for the positioning and the achievable flexibility of this configuration has been accomplished in many applications of robotics. In combination with the dynamic counterweights the driving mechanics could be preserved, and the precision could be improved. (Lauer, 2009) The particularity of this geometric configuration can be identified by the fact that an object placed within the beams for the Euler Rotation can be reached from any outside direction. From this, it can be derived, that any point on a bowl or another geometric object can be reached. (Lauer, 2009)

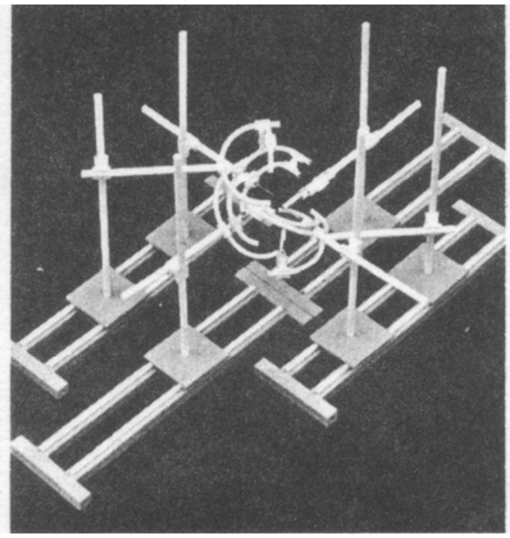
Fig.6: Geometric characteristics of the LOM, reconstruction by the author

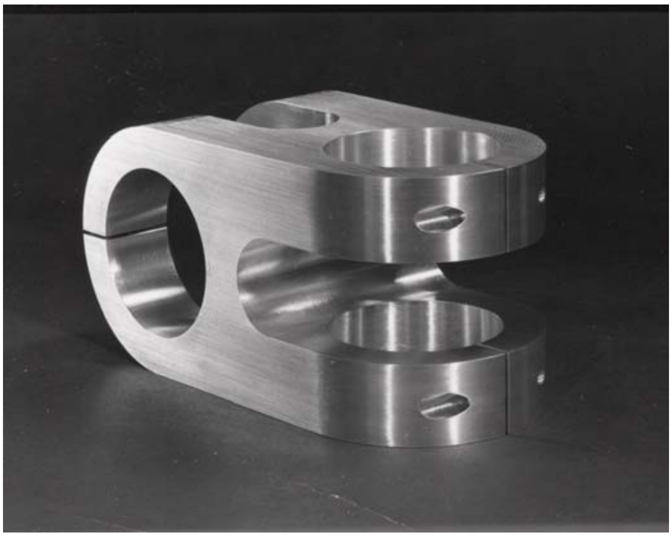


Characteristics of the LOM configuration

The kinematics of the LOM is modularized within a certain degree, so that it can be adjusted to various requirements, without the need to construct a totally new manipulator. Moreover most of the parts and crosspoints can be exchanged, added or removed to make it suitable for different applications. The three euler rotations can be realized by using the same protypic crosspoints of which each of these can be rotated around one axis. This modular way of construction allows the use of more or less crosspoints depending on particular needs to realize more or less degrees of freedom. (Lauer, 2009) The use of dynamic counterweights for the euler rotations and the horizontal translation reduces the loads of the moments at the crosspoints and allows to reduce the material used for the excentric connections to a minimum. Possibly it is this innovation, which enabled the design of very similar, or even identical crosspoints for each of the connections (besides the basepoint). Notably, a combination of several LOM units to form a complex central processing and assembly unit has been planned already, and was easily to realize, as the modularization of the manipulator has been considered since the very beginning of the studies. „The physical independence of each unit allows to arrange a number of LOM devices in different conjuctions.“ (Maier, 1989)

Fig.7: Configuration of several LOM, räumliche syntax; Fig. 8, crosspoint of the LOM, KWA





It is the consideration of the three elementary aspects of geometry, physics and function of the entire structure and all parts, that gives the LOM its unique design and high rate of flexibility. It can be identified within the single parts, as well as in the overall structure.

Conclusion: Integral building research

As broad the field of application of the LOM for research and development can be estimated, its direct use for building applications can be put into doubt. Nevertheless it was the intention of Konrad Wachsmann and his team to start with a kind of abstract and empirical research to use it as a basement for further developments. Unfortunately this research was stopped after the dissertation of John Bollinger and Xavier Mendoza, even the Location Orientation Manipulator remained in some boxes for the last 30 years and finally got lost. (Lauer, 2009)

Based on the only remaining video, of the LOM, donated to Prof. Bock by Fritz Haller, since 2009 at the Technical University of Munich, this device is being reconstructed to eventually continue with the research of architecture and building specific trajectory planning and kinematics. Until now the lack of highly sophisticated assembly systems for building and construction applications, cannot be overseen. (Lauer, 2009)

The example of Konrad Wachsmanns LOM shows his mode of operation, to balance different requirements and achievable characteristics of subsystems and the entire project besides formal criteria, in a way, that the final project forms an open system and has a flexible spectrum of characteristics. Therefore his work and his studies were oriented towards a high grade of interdisciplinarity. “Integral building research requires a close cooperation of several disciplines, and requires another state of awareness than research which is performed only in one single discipline. It implies a method of research and planning, which is oriented from the single problem towards the whole thing.” (Maier, 1989) This way of considering the interdependencies and interfaces of different technologies, materials and concepts can be identified in the current field of research called robot oriented design. (Bock, 2010)

References:

1. Prof. Thomas Bock, Lehrstuhl Baurealisierung, TUM
2. Wachsmann, Konrad: Wendepunkt im Bauen. Reprint of the 1959 in Krausskopf Verlag, Wiesbaden, published version, VEB Verlag der Kunst Dresden 1989, S.52
3. Lauer, Willi, Location Orientation Manipulator, Diplomarbeit at TUM, Munich 2009, pp 100- 140
4. Letter of Xavier Mendoza, Konrad Wachsmann Archive Berlin (KWA), Schub 2/28, 1969
5. Interpretation based on KWA Schub 2/28
6. Maier, Otto: Die räumliche Syntax, Dissertation, Karlsruhe, 1989, p.321
7. Interpretation based on Maier, Otto, Räumliche Syntax, p.321
8. Dissertation of Xavier Mendoza, Oral Examination, KWA, Schub 2/28, 1971
9. KWA Schub. 2/29, request of a light manufacturing company, to buy the LOM
10. Maier, Otto: Die räumliche Syntax, Dissertation, Karlsruhe, 1989, p.321
11. in Bezug auf das Modell im Maßstab 1:2,5 des LOM
12. Maier, Otto: Die räumliche Syntax, Dissertation, Karlsruhe, 1989, p. 61