Random Lego(TM) Structures and Analog Monte Carlo Procedures

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Abstract

Recently we discovered a phenomenon: When filled with many single Lego bricks, a washing machine generates random complexes. This analog generation process may be used in Monte Carlo-based procedures for building new Lego structures and for interactive "generative design". Our work and also this report are preliminary and tentative.

Key Words: random Lego(TM) structures, analog Monte Carlo procedure, generative design;

1. Introduction

Within a larger experimental series we put a whole bucket of old Lego(TM) bricks (from the late 1960's and the early 1970's) into our Miele(TM) washing machine [1]. They were treated for 70 minutes, at 40 degree Celsius, without spinning, without washing powder. At the start we had disintegrated all complexes. So, only isolated bricks were put in the machine. During the procedure many "stable" complexes arose: most of them consisting of two bricks, but also others with up to six pieces in it. In many such complexes, plates of sizes 2x8 or 4x8 or 6x8 were involved.

The washing machine together with Lego bricks is a primitive **analog Monte Carlo agent**. From the viewpoint of other disciplines it may also be viewed as

* a model of the Miller-Urey experiment on amino acid formation in primordial soup (Chemistry and Biology). See also [2] for the description of such experiments.

* a system visualizing aspects of entropy, decay, and spontaneous self-organisation (Physics, Chemistry).

* a tool in a new branch of machine-assisted modern art.

The report is organized as follows. In Section 2 we describe three different games, based on the formation of random Lego complexes. Section 3 lists Lego approaches by other researchers.
In Section 4 we discuss our experiments in more detail. The paper finishes with a short conclusion and outlook.

2. Games with Random Lego Complexes

Using a washing machine as a generator of random Lego complexes, several games may be played. For some of them, algorithms like pure Monte Carlo, MCTS (Monte Carlo Tree Search) or UCT may be useful tools.

2.1 Lego Washing Roulette

At a University party I described the Lego washing procedure to a handful of doctoral and Master students. We had a washing machine at hand, also a bucket full with basic Lego bricks (about 400 pieces). We directly played the following game. Before washing, each participant had to predict one possible complex that would result from the washing. The referee (= this author) took photos to document the choices. Colours did not play a role, but simply the brick shapes.

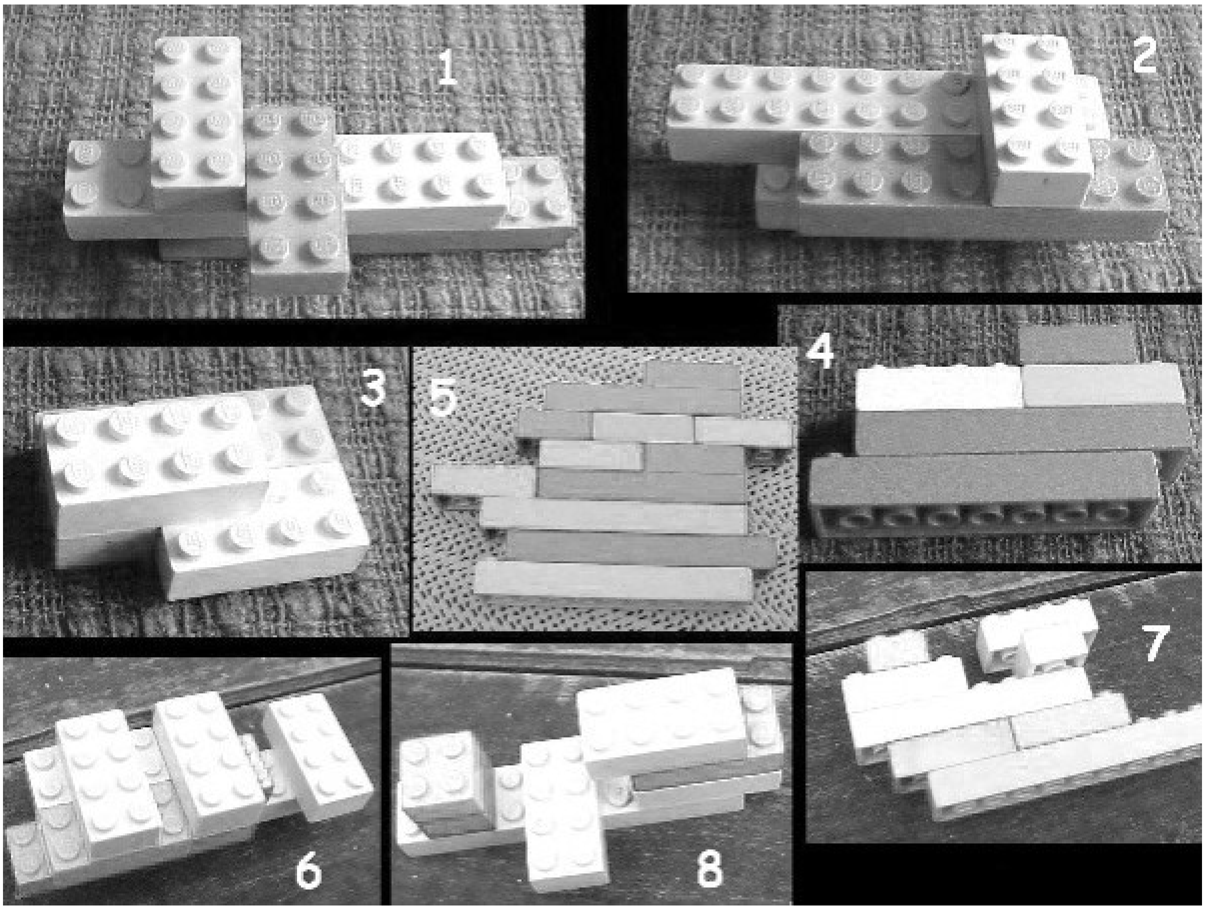

Figure 2.1.1 Predictions by eight players who had no experiences with Lego in washing machines.

After the washing, we would find out which of the predicted pieces had been built. Winning candidates would be all players whose complexes were found. Among them, winner would be the player whose complex had most bricks. Ties would be broken by majority voting on the beauty of the complexes. Players 1 to 3 had proposed small complexes (with four bricks each), all others had opted for much more complicated structures. The result was disillusioning: Not a single one of the eight complexes came out of the machine!

Figure 2.1.2 Complexes from the party Lego washing

2.2 Lego Enzyme Game

A set of (isolated) Lego bricks in a washing machine leads to interesting random complexes. Like in chemistry or in biology, catalysts or enzymes may speed up a reaction or increase the production rate of interesting complexes. Of course, it might be possible that these enzymes are themselves Lego complexes.

After having digested the no-winner shock of the game in Subsection 2.1, two biologists from the group proposed another Lego washing game. Their idea started when they saw one of the complexes that had been built. Immediately they exclaimed: This might be an enzyme!

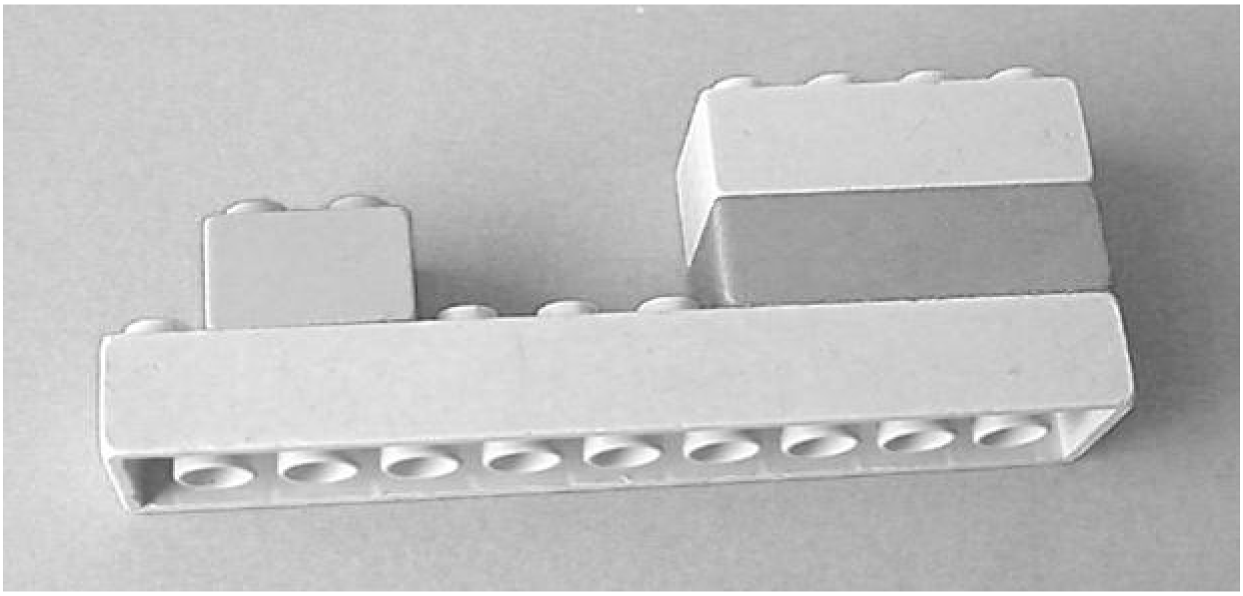

Figure 2.2: A Lego enzyme candidate ?!

The proposed game has one run for each player. He is allowed to use for instance a total of 50 bricks to form one or several artificial complexes which are added to the original set of bricks. The player is basically successful when these artificial complexes are still unchanged/functional after the washing, so like a "true" enzyme. And he is really successful when lots of nice complexes have been created in addition.

2.3 Solitaire Generative Design Game

"Generative Design" [3] is a design method in which the output is generated by a set of rules or an algorithm, normally by using a computer program with some probabilistic elements. Typically generative design has a (probabilistic) mechanism for creating variations and a procedure of selecting desirable outcomes. Often the selection is done by a human controller.

Concretely with Lego in a washing machine, generative design might be organized as follows. Each round consists of one washing run, followed by human selection of nice complexes in the yield. Before starting the next run, the human may create additional identical copies of the (relatively) nice complexes (for instance with additional bricks) and include them in the "pool". This intervention simulates reproduction of fit species in a biological system. The hope is that in the next run (nice) mutants of these nice complexes will be generated. Again the player can select the nicest ones and replicate them. In some test runs we observed a problem: When the clutch power of the bricks is no longer strong, complexes (even with 3 or 4 bricks only) are in high danger of decay in the next washing run. See also Section 4.1 on this phenomenon. The number of rounds is not necessarily fixed. The human may stop at any time when a really nice complex has evolved - or when he has lost hope for satisfying results. Observe: Generative design with its human intervention has to be clearly distinguished from "Generative Art" where a fully automatic design process is assumed.

3. Related Work by Others

3.1 The Lego Brick Layout Problem

In [4], P. Petrovic described how he had used evolutionary algorithms to tackle the "Lego Brick Layout Problem" which had been posed by the Lego company itself: Given any 3D body, how can it be built from LEGO bricks? Petrovic used Evolutionary Algorithms with digital models of Lego complexes to solve the problem satisfactorily.

3.2 Evolving Lego Brick Structures

P. Funes and J. Pollack ([5],[6]) investigated computer-aided design of stable Lego structures (for instance cranes) by the help of evolutionary algorithms. Their software EvoCAD combine a simple evolutionary algorithm with a partial simulation of Lego bricks statics to evolve designs that come out of the computer ready to build.

3.3 Counting Lego Complexes: Exactly and Asymptotically

From the viewpoint of combinatorics, M. Abrahamsen and S. Eilers [7] counted the number of all possible connected complexes with exactly k mono-colored Lego bricks of size 4x2, for small values of k. Most prominent has become their value 915,103,765 for k=6. B. Durhuus and S. Eilers proved asymptotic bounds on the number of configurations for general k, see [8]. In [9], a popular description of the counting approach(es) of Abramsen, Durhuus, and Eilers is given.
Our experimental findings on “superstable” complexes with 4x2-bricks in Subsection 4.1 below indicates that only very very few of all the many complexes are so stable that they build and survive

in harsh environments like a washing machine.

3.4 Software MLCAD for digital Lego design

Within the international scene of adult Lego fans, free software has been created which allows to build Lego complexes on the computer screen [10]. R. Beneke gave me an introduction by providing a simple code (based on Excel code) which generates random Lego towers with exactly one 4x2-brick in each layer.

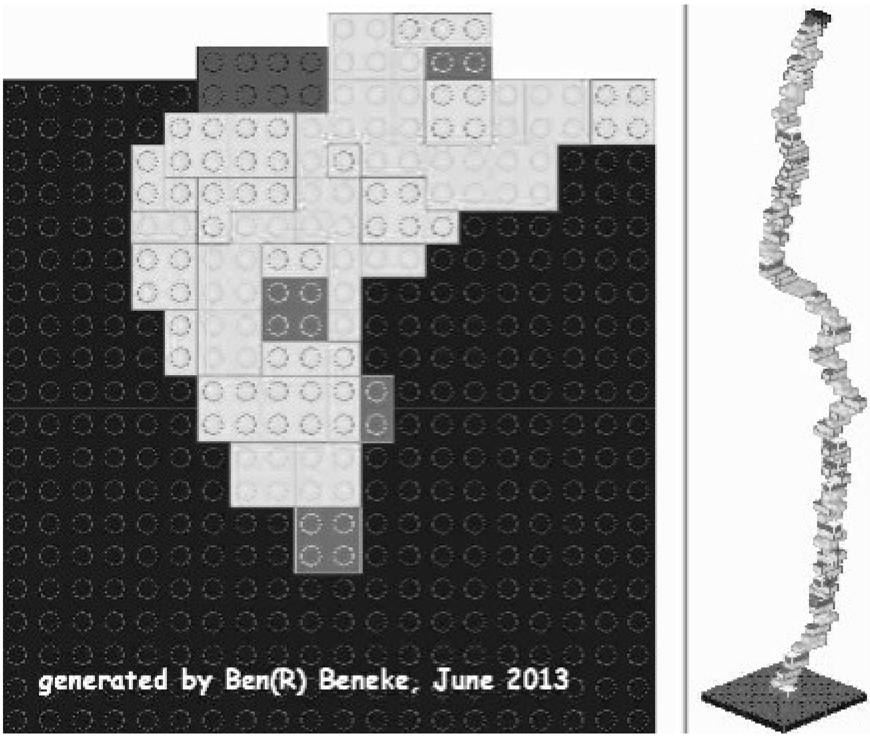

Figure 3.4 A random tower from 100 4x2-bricks (screenshot by R. Beneke).

4. Miscellaneous

4.1 Complex Generation and Decay

When starting with isolated bricks, there is only one way: complexes can form. However, as soon as the first complex is there it can also decompose again by the shaking and stirring. In the long run, some equilibrium should be realized where generation of complexes and decay are in balance.

We did some experiments with simple sets of bricks to find out about the nature of this equilibrium. We took 326 old bricks of size 4x2 (of different colors, but the colors were simply ignored). After 70 minutes of washing many complexes were found, but only very few different types. Figure 4.1 shows the whole yield. This result is especially interesting in contrast to the huge number of different complexes that can be formed with a few bricks (for instance more than 900 million different structures with six bricks [9]). A washing machine seems to have only rather limited fantasy. On a website [11] we describe more experiments on the balance between complex building and decay in Lego.

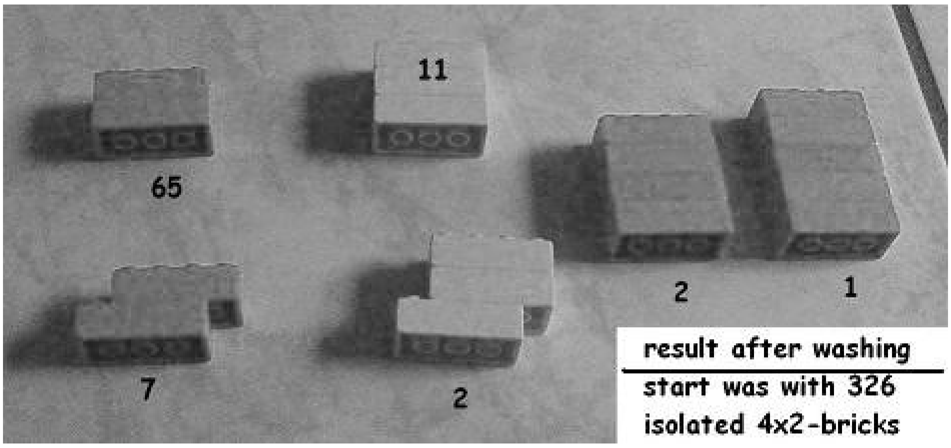

Figure 4.1 “Superstable” Lego Complexes from 4x2-bricks

In another run we started with 65 simple 4x2-towers, each one 5 bricks high. Most of the towers disintegrated. After the washing, almost all pieces were found in isolated bricks and simple towers of heights 2 and 3. We were most surprised that the only "remaining" height-5 tower had a color composition that had not been in the original "seed"! No towers of height 6 or more had been formed and survived. Analogous tests with 3x2- and 2x2-bricks gave similar results, with fractions of isolated bricks decreasing with the size of the bricks. In average, 2x2-bricks gave the smallest complexes, and 4x2-bricks the largest ones.

Varying levels of shaking may yield an effect like in the “Simulated Annealing” algorithm. In particular, decreasing levels of shaking may help to conserve interesting complexes that have been created in an early phase.

4.2 Miller-Urey Type Experiments with Lego

On May 19, 2013, I had done some testing with Lego bricks in water [2]. It turned out that it was not trivial to dry them afterwards: I shook them in a towel and placed them in the afternoon sun for half an hour. But still, there were little water drops left inside of the bricks. To accelerate their evaporation I put the bricks in a box and did the stirring. Then my eyes fell on the complexes.

Immediately I saw a cross relation to the Miller-Urey experiment [12] on the primordial soup. Stanley Miller had simulated conditions during the early phase of earth by putting water, methane, ammonia, and hydrogen together in a closed system of glass flasks. He added heat, stirring, lightnings; the result after a week was a soup which contained lots of amino acids, the building blocks of terrestrial life .

Only in that evening, a web search taught me that Miller's article had been published in "Science" on May 15, 1953. This means, I had missed the 60th anniversary by only four days!

4.3 Washing Machine and Art

Lego in the washing machine was a joint human-machine art activity. It was the human's task to fill ths bricks in the machine, decide for the program (40 degree Celsius, no spinning, no washing powder), and - now comes the creative part - to interpret the complexes at the end and find names for the nicer ones. The machine had nothing more to do but generating the random complexes.

In the very first run two beautiful complexes resulted: Art Emiele I and II. The funny thing is that different people have rather different associations when looking at these complexes.

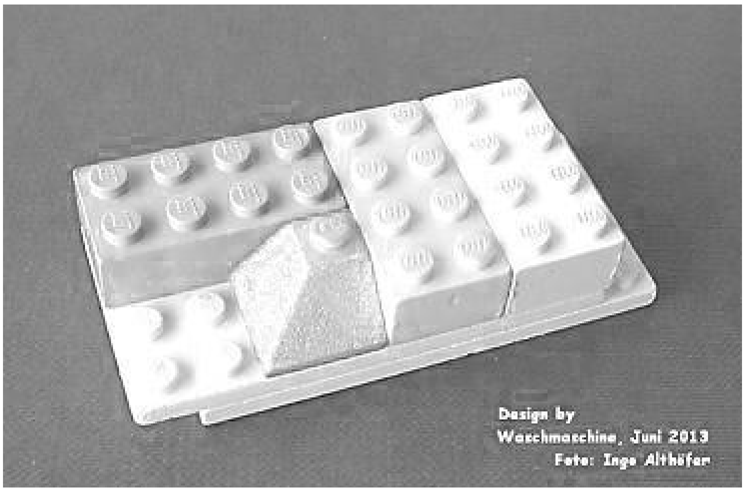

Figure 4.3.1: Art Emiele I - is it a little Mondrian, or a specific skater park in Munich, or a heavy lift crane with broken arm (the red brick being the cabin for the crane master)?

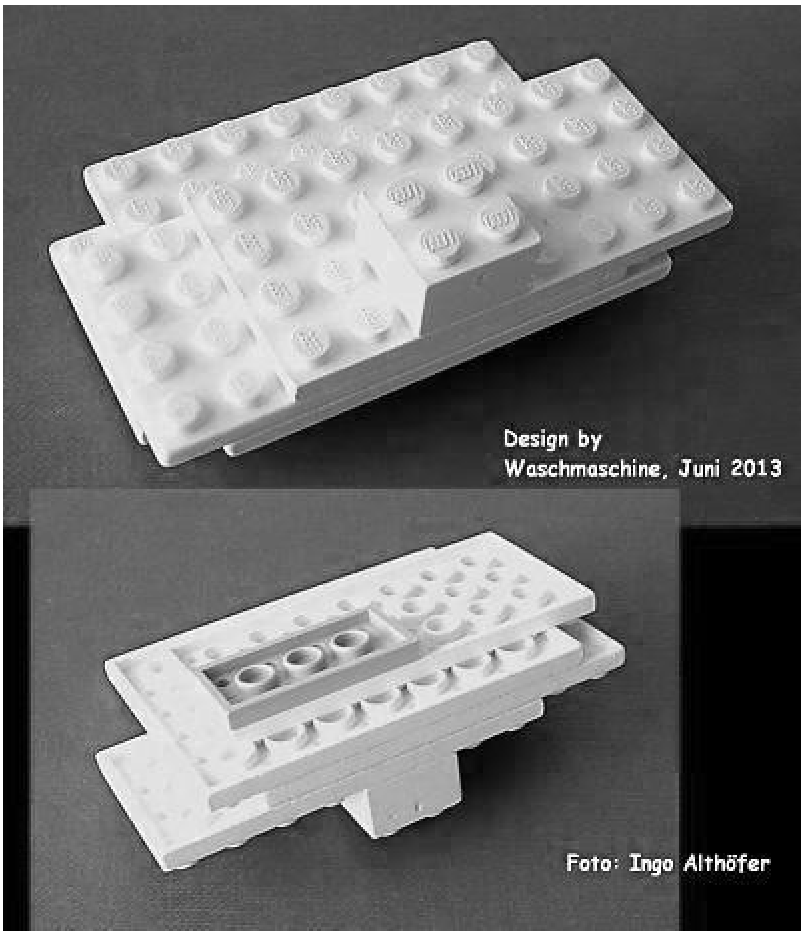

Figure 4.3.2: Art Emiele II - for me the white object clearly was an aircraft carrier. Other interpretations were: a mathematician's desktop with lots of papers in a slight mess, a newspaper rack (when standing in upright position), or the modern Elbphilharmonie (a prestige building in Hamburg, not complete yet).

Some operators even like to watch their machine during the washing procedure.

Figure 4.3.3: Deputy operator Prof. Dr. J. Woestemeyer in front of his washing machine. Later in the party he was firmly convinced that one of the complexes might give a good enzyme for further washing processes.

5. Conclusion and Outlook

Future will show, if this report is the starting point of a lively development or some isolated strange event. Our hope and expectation is that at the end of 2013 we will have collected much more knowledge and discovered many more aspects of random Lego structures.

5.1 **Hopes on the Computational Intelligence Scene**

It is my expectation that the "Computational (Games and) Intelligence" scene will soon find applications where the analog generation of random Lego complexes is a useful part.

5.2 Difficulties in the Experiments

A Lego brick after ten runs in a washing machine is clearly different from the very same brick before the ten runs. This makes the interpretation of experiments difficult, concerning the aspect of reproducibility. Experiments with new bricks result in only very few nontrivial complexes, because the clutch power is still too strong for allowing random connections. However, in a stand-alone side experiment, 30 minutes of fiddling around with seven green 8x6-plates made them being old.

5.3 Related Experiments with Other Toys

Similar analog experiments are possible with other toys, including Lego-compatible bricks with different degrees of clutch power. See for instance work by Hosoka et al. mentioned in [12, p.256] where parts simpler than Lego were under investigation.

5.4 Lego Sedimentation
Taking a big Lego plate, we made preliminary experiments on "Simulated Sedimentation": larger amounts of Lego bricks are moved by hand over the plate several times, and each time some of the bricks get clutched.

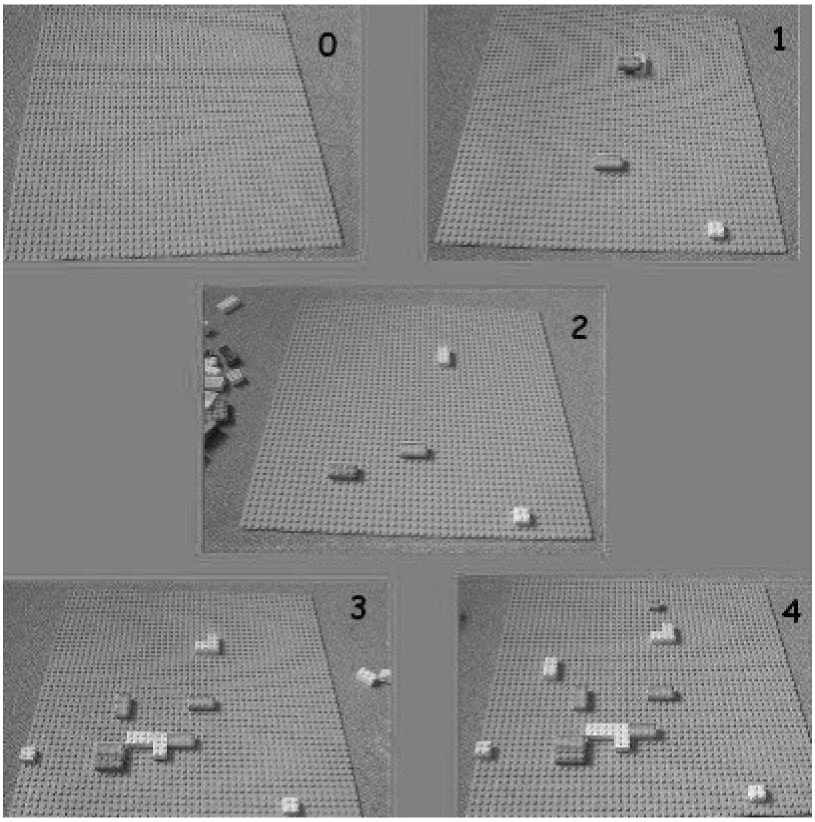

Figure 5.4: Lego sedimentation on a grey plate after four periods of flowing.

5.5 Lego in Analog Random Number Generators
In the computer-go mailing list, Brian Sheppard proposed [13] to use a washing machine with Lego bricks as an analog random number generator: take digital photos through the process of washing and spinning, and hash the images using a cryptographically strong hash function.

5.6 Lego Science in Schools and Families
It is our hope that thousands of children and adults will execute their own Lego washing and shaking experiments. Many of them will definitely find new aspects - at least new random complexes - and hopefully share them with us. Open question: Are there suitable sets of Lego bricks where typically complexes with ten or more bricks are composed by the washing machine? “Traditionally”, there is a difference between Europe and the United States in acceptance of Lego as a useful and serious tool in education. Hopefully, our approach will help to close the gap between unprejudiced “Yankees” and conservative Europeans.

5.7 Stability Analysis of Lego Structures
M. Wassmann and K.Weicker used network flow methods for the stability analysis of Lego structures [14].

5.8 Lego Science vs. Nano Science
Random Lego processes may be compared with processes of (random) nano particles [15].

5.9 Warning: Do not use very small or fragile Lego pieces for washing sessions! They may enter unappropriate regions of the washing machine and cause damage there.

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Several friends and colleagues shared my enthusiasm and helped with hints, proposals, critical questions, and discussions. Thanks go to Cameron Browne (he found several interesting Lego science links) and Chrilly Donninger, for accepting my Lego washing essay for the June 2013 issue of his monthly goldprice report. Andreas Dress allowed me to make a Lego shaking presentation during the celebrations of his 75th birthday in Leipzig's Max Planck Institute for Mathematics in the Natural sciences. From the chemists Ernst Anders (Jena), Rolf Saalfrank (Erlangen) and Jan H. van Esch (Delft) I got stimulating feedback on spontaneous self-organization ([16], [17]).

Johannes Wöstemeyer (Chair of Micro Biology at Jena University), like me, has always protected the playing child within him and opened his private washing machine for more Lego runs. Thanks to my wife Beate for her never ending patience, and to R. Beneke and the AFoL (Adult Fans of Lego) scene in general, for their inspiration. Special thanks go to the Friedrich-Schiller University and their wise president Prof. Dr. Klaus Dicke for tolerating and encouraging strange science interests.

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