OPBPO output is a series of orientations with minimum build time and support volume satisfying the desired surface finish. Figures 7, 9 and 12 are the outputs for some sample cases.

A question that may arise here is why do authors think Pareto methods like OPBPO are preferred to traditional GAs, where all objective functions are abstracted to a single fitness function? To answer this question, it should be mentioned that parameters such as build time and support volume are not congruent objective functions. Therefore, adding them in a single fitness function cannot show the roll of each objective function properly to evaluate the optimum part orientation. In addition, the output of traditional GAs is one unique optimum direction. OPBPO applies the build time and support volume as independent objective functions to provide a group of optimum directions. Because a family of optimum solutions is presented, the user can select among the solutions.

5 Case Studies

To find out the functionality of OPBPO, the algorithm is run for several cases. Fig. 7 illustrates the solid model and STL model of a perfume box. The minimum and maximum allowable layer thickness are 0.05 mm and 0.2 mm, Ra is 0.1 mm, h_s =0.25 mm and the laser power is chosen to be 50 mw. MATLAB toolbox uses MOGA method as the multiple objective evolutionary method to solve optimization problems. The MOGA parameters are listed in Table 1.

Parameters	**description**
Population Ssize	20
Number of Generation	20
Crossover Fraction	0.8
Migration Fraction	0.2
Elite Count	2
Scaling Function	Rank Method
Population Type	Double Vector

Table 1 MOGA parameters in OPBPO for case studies

Table 2 shows OPBPO non-dominant solutions data including part directions build time and support volume. Fig. 8 is the plot of non-dominant solutions.

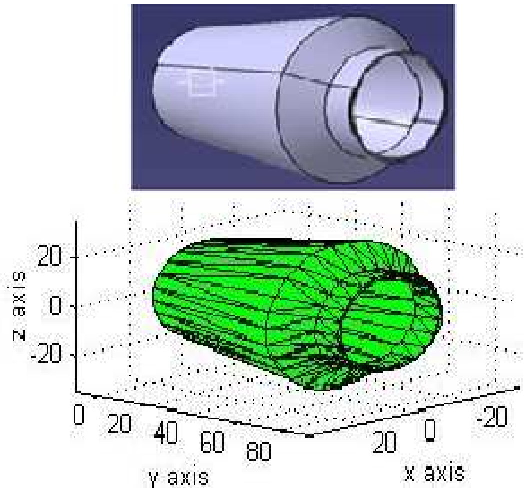

Fig. 7 Solid and STL model of the electronic part

Directions	θ_x (Degree)	θ_y (Degree)	Build Time (hr)	Support Volume $\left(cm^3\right)$
1	164.33	59.24	3.799	10.436
2	115.98	102.15	4.006	7.834
3	115.98	99.34	4.022	7.275
4	132.72	82.50	4.457	5.663
5	128.73	82.15	4.411	6.713
6	165.49	66.440	3.896	9.898
7	126.79	80.97	4.296	6.990

Table 2 OPBPO non-dominant Pareto optimum solutions of perfume box

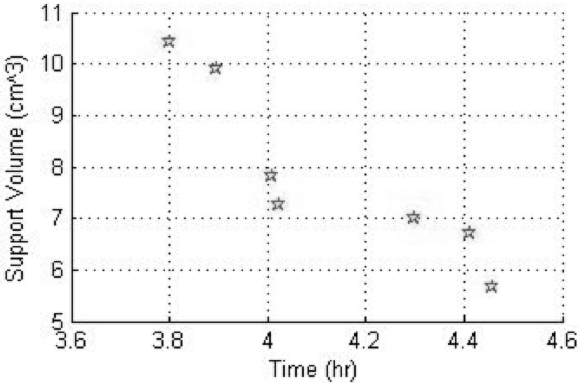

Fig. 8 Build time and support volume for non dominant directions of perfume box

The OPBPO proposes optimal orientations as Pareto front solutions (directions). These directions are not dominated by each other but are the best direction among all other directions in orientation space.

The next case study is the body of mouse. The CAD model and STL view of the mouse is seen in

Fig. 9. Optimal directions are seen in Table 3. Comparing the first and second solutions in Table 3, the build time for the first solution is more than the second one, but the support volume is less. However all of them are non-dominant solutions. This is the strong point of OPBPO. The user can choose the proper orientation based on his/her needs. In Fig. 10, the build time and support volume for the optimal directions are depicted.

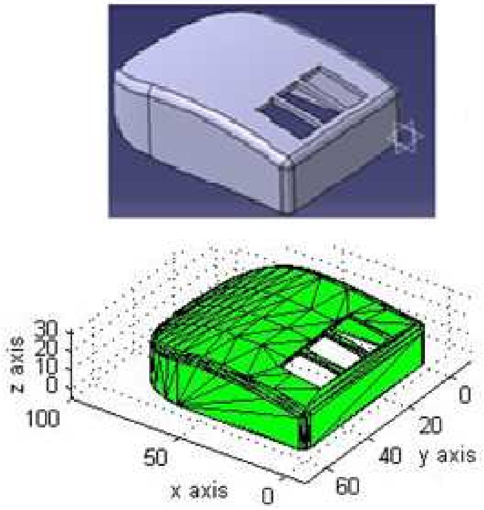

Fig. 9 CAD and STL model of the body of mouse

Directions	θ_x (Degree)	θ_y (Degree)	Build Time (hr)	Support Volume (cm^3)
1	0	180	2.4651	32.0392
2	196.31	90.34	4.1410	13.931
3	219.95	90.45	4.2561	3.3319
4	217.1420	90.45	4.2513	3.3729
5	143.20	99.66	4.7515	2.4551
6	185.61	89.01	4.1044	21.0537

Table 3 Pareto solutions of the mouse

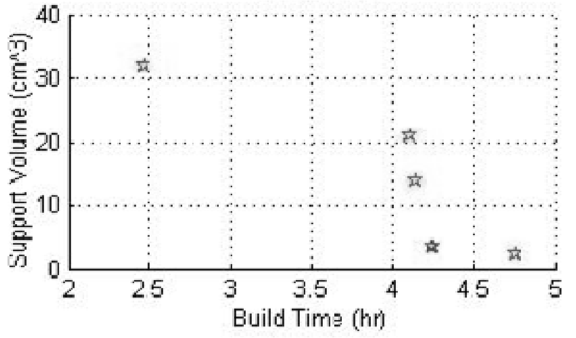

Fig. 10 Build time and support volume for non dominant directions of the body of mouse

The other case study is an electronic part (200×80×30 mm). Its CAD and STL model have been shown in Fig. 11. In Table 4 and Fig. 12 are the non-dominant solutions. The input parameters are similar to the first case.

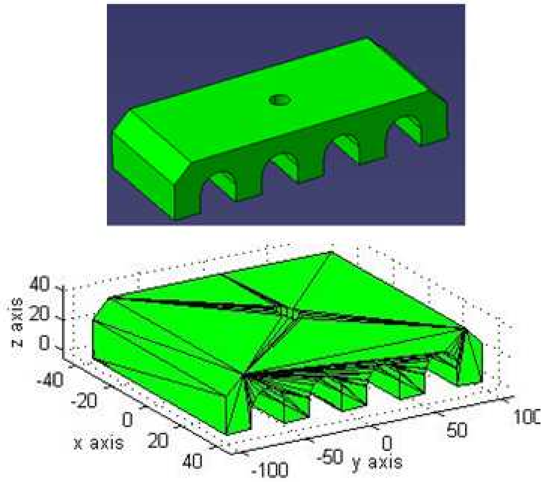

Fig. 11 STL model of the electronic part

Directions	θ_x (Degree)	θ_y (Degree)	Build Time (hr)	Support Volume (cm^3)
1	95.25	89.95	20.84	35.60
2	181.14	89.93	20.70	38.25
3	94.03	89.935	20.83	36.13
4	102.13	89.93	20.95	30.14
5	316.18	89.673	23.02	25.5
6	102.13	89.93	20.95	30.14
7	101.46	89.952	20.92	31.84

Table 4 Pareto solutions of the electronic part

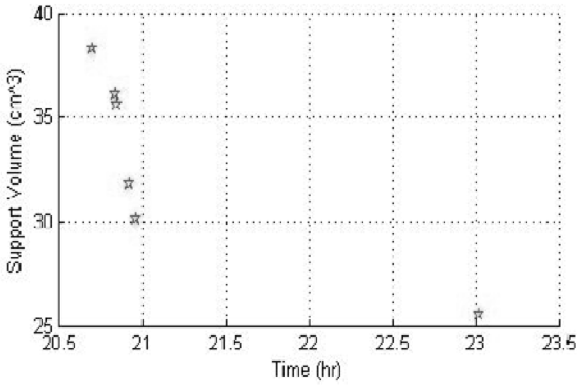

Fig. 12 Build time and support volume for non dominant directions of the electronic part

Skipping the small variations of θ_y in Table 4, due to calculation errors, the optimum solutions do not depend on θ_x. To clarify the result, the initial direction of the part along with seven optimum directions in Table 4 are pictured in Fig. 13. As the figure shows, when $\theta_y = 90$, changing θ_x will not have any effect on the build time and support volume. This is because the cross section of the part is identical for all sections parallel to xy plane. The diversity of answers for θ_x also proves this result. In fact the number of non-dominant answers here are infinite. This case study can be considered as a sample part that future shows the ability of OPBPO method to find the unique optimal build-up direction on the machine.

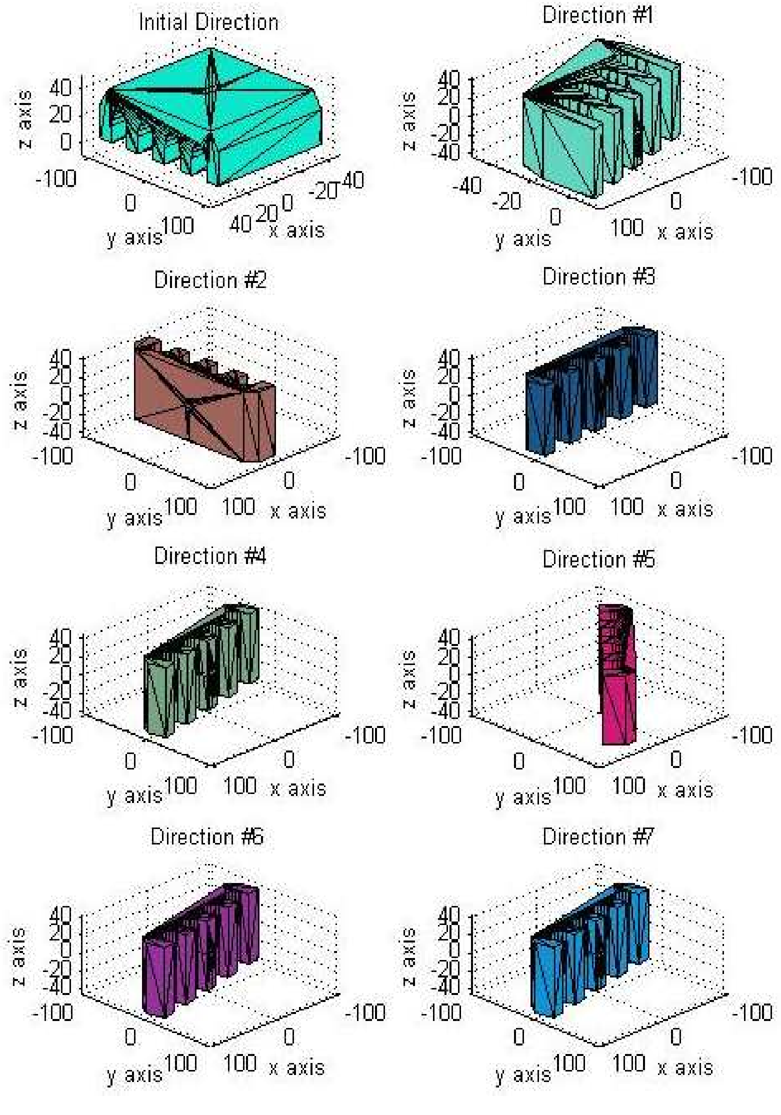

Fig. 13 The initial and optimum directions for the electronic part

6 Conclusions

OPBPO is proposed to compute the optimum part orientations with minimum build time and support volume as well as desired surface finish. It employs adaptive slicing method along with Pareto based multi objective GA to handle the parts. OPBPO provides a series of best part orientations while optimizing objective functions both simultaneously and independently.

OPBPO functions quite well for exceptional parts, where there is a unique optimum direction satisfying both minimum support volume and build time. This promising feature is illustrated in the electronic part in Fig. 13.

Previous studies have shown that surface finish is more important in comparison to build time and support volume. It has a direct effect on die quality, produced through RP. Build time and support volume mainly affect cost. OPBPO considers surface finish a priority via the adaptive slicing method. The build time and support volume do not have a conceptual relationship to be considered in a unique fitness function. OPBPO can evaluate them independently as the second priority items.

The algorithm was run for different parts. The method has been shown to work for simple parts such as rectangles and cylinders. The results are also impressive for complex parts.

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